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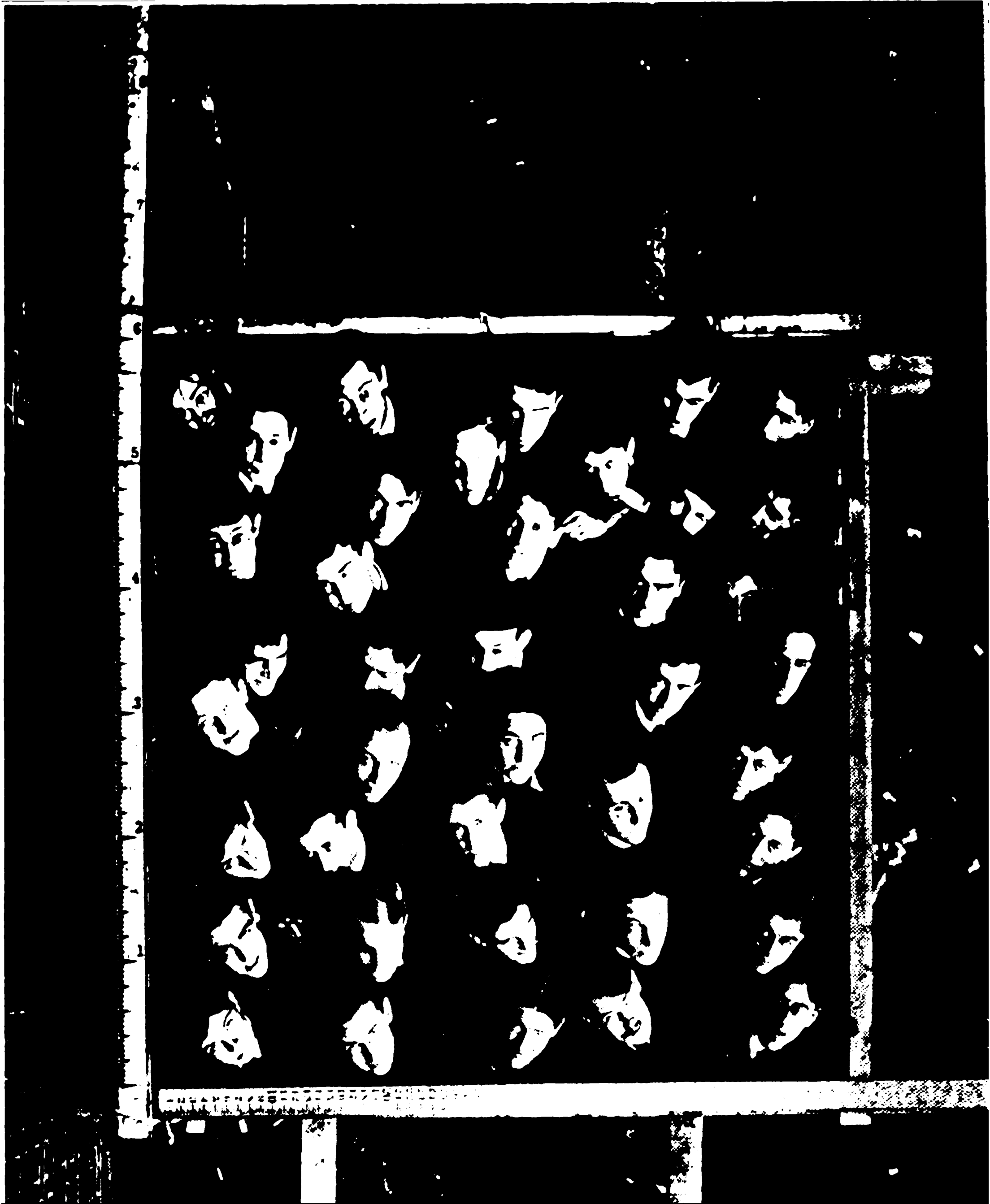

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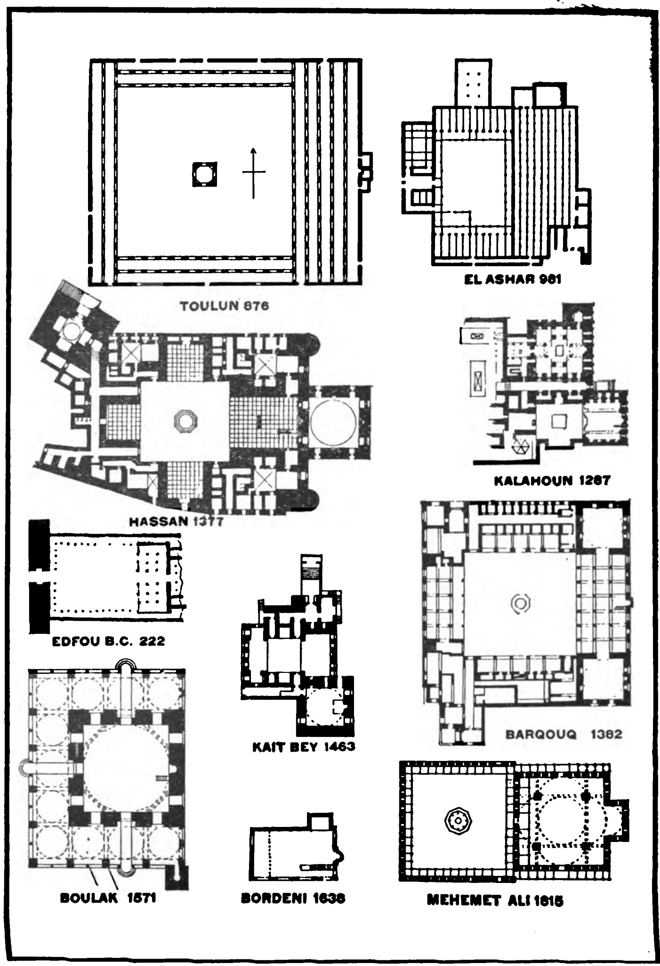

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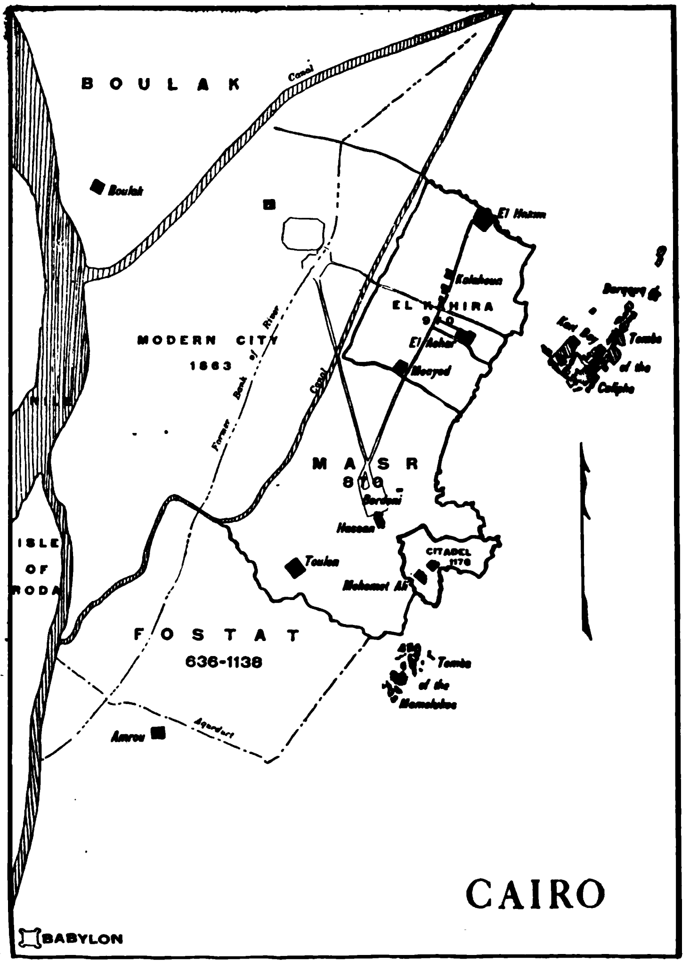

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NOTE.

The Historical Table prefixed to this paper gives at the top the date of the Hegira, of the death of Mahomet, and of the accession of the "Four First Caliphs" who succeeded him at Medina.

Below are given the names and dates of the successive dynasties which have held sway in Egypt from that time to this, in nominal subjection to the Ommiad, Abbasside, and Turkish Caliphs, who have inherited, or assumed, the spiritual authority of the founders. The table contains the names of the principal sultans and of the more important of the Cairo mosques and their plans are given, and their position in the city shown, in Plate I.

In a second column are given the principal contemporaneous events of Mohammedan history outside of Egypt, so far, at least, as they concern the immediate object of this paper. It marks the duration of the Ommiad, Abbasside, and Turkish caliphates.

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SARACENIC ARCHITECTURE.

BY PROFESSOR WILLIAM R. WARE, '52.

I.

MAHOMET was an Arab chief, and the Arabs were barbarous tribes of the desert with no art, and no materials for art, except for the art of poetry. Painting, sculpture and architecture were alike unknown to them. In Egypt they came in contact with the Byzantine Empire, and with what remained of the civilization of the Roman Empire and of the Greek Empire of Alexander, and, what was more important, with what remained of the old Egyptian civilization, an influence which already had produced marked effects not only upon the Romans and the Greeks, but upon the Jewish colonists who had settled in Alexandria. Meanwhile the peculiarly mystical turn of the Egyptian mind had affected both philosophy and religion, and to this day it affects the philosophy and religion of all Christian countries.

The Hegira, or flight of Mahomet from Mecca to Medina, took place in the year 622, and he died in 632, ten years later. The first Caliphs, the successors, of Mahomet, were his father-in-law, Abu Bekr, his generals, Omar and Othman, and his son-in-law, Ali. They are known in history as the Four First Caliphs.

NOTE.— The substance of this paper is taken from a lecture given at the Metropolitan Museum, in New York, in February, 1899, and again in Cambridge, before the *Pen and Brush Club*, in March, 1904.

Some of the figures in Plates XI and XII are taken from M. Gayet's "*Art Arabe*," a volume to which I am indebted also for much information. The rest are taken mostly from photographs, and from sketches made in Egypt and Asia Minor in 1890.

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They established and maintained the caliphate at Medina for thirty years. It was the caliph Omar who, with his General Amrou, conquered Egypt and burned the Alexandrian library, or is said to have done so; the next, Othman, belonged to the Ommiad family, of Medina. The fourth caliph was Ali, the husband of Mahomet's only child Fatima, and the disputes which followed his accession have divided the Mohammedan world to this day between the Sunnites, or orthodox Mohammedans, and the Shiites, or Fatimites, the followers of Ali. The Shiites, though adhering to the only descendants of the prophet, are held to be heretics and dissenters.

At the end of the thirty years, that is to say in the year 662, the Ommiads, of the family of Othman, murdered Ali and his two sons Hassan and Hussein, and removed the caliphate to Damascus, where it remained for ninety years. It is rather singular that although Hassan and Hussein belonged to the hated sect of the Shiites, they are held in the greatest veneration by the orthodox Sunnites. They are the most revered of Mohammedan saints and martyrs, and the day of their death is everywhere celebrated with tumultuous demonstrations of grief. Even in London, the Mohammedan sailors make the docks resound with their lamentations. The martyrs Hassan and Hussein are known in Cairo as the Hŏsaneyn. By the unbelieving inhabitants of East London, they are called Hobson and Jobson.

In 750, the descendants of Mahomet's uncle, Abbas, came to the front, and in their turn murdered at Damascus all the Ommiads but two. One of these escaped to Southern Arabia, where he founded an Ommiad Caliphate which lasted 800 years. The other, Abd-er-Rahman, a little boy, fled to Spain and founded the caliphate of Cordova. At the same time the Abbassides moved the orthodox caliphate from Damascus to Bagdad, where they reigned for five hundred years until, in 1250, they were conquered by the Mongols, or Moguls, and took refuge in Cairo, where the caliphate remained until the sixteenth century, when the Turks took possession and carried it to Constantinople.

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Meanwhile Musa, a Mohammedan general of the Ommiads, conquered the north of Africa. This conquest is about the only important event with which to mark the year 700. In 711, Tarik crossed the Straits of Gibraltar, which takes its name from him, Gebel-el-Tarik, the Hill of Tarik, and conquered Roderick, "the Last of the Goths," in the battle of Xeres. In 732, spreading into France, just a century after the death of Mahomet, the Arabs were defeated by Charles Martel in the battle of Tours. Thus, it is held, was France, and in fact the whole of Europe, rescued from Mohammedan control and perhaps from the Mohammedan religion.

Finally, the Turks, in two bodies, seized Syria and Asia Minor. The Seljukian Turks who maintained themselves at Iconium in Lycaonia during the twelfth and thirteenth centuries, were followed at the beginning of the fourteenth century by the Ottoman Turks, who established their capital at Broussa in Bithynia, fifty or sixty miles south of Constantinople. They took Constantinople in 1453, and fifty years later conquered Egypt, and the Turkish Sultan assumed the title of caliph. The principal monuments of the Turks are their mosques at Constantinople.

We will here consider only the Mohammedan architecture which was the best claim to be called Saracenic, that of Egypt. It was not only the earliest, but, being the first, it gave tone and character to the architecture of every country which the Mohammedans conquered. Everything in Spain, Persia and even India seems to have obtained its main inspiration from the architecture of Egypt.

In the year 638 Amrou, the general of the caliph Omar, conquered Egypt, and in 642 founded a town near the old Roman fortress called Babylon, which stood on the eastern bank of the Nile, just below Memphis, at the head of the Delta. He then proceeded to the conquest of Alexandria, but as he was striking his tent, he noticed that a couple of doves were building their nest on the top of it, and ordered that they should not be disturbed. On his return from Alexandria the tent was still standing. "Fostat" is the Arabic word for "tent," and he called his town Fostat, the town of the tent. (Plate I.)

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The mosque he built there is the oldest in Cairo. But it has been rebuilt so often, that the present Mosque of Amrou shows few traces of the original structure. (Plate II).

It constantly happens that the earliest remaining monuments of any civilization are already of mature character. The earliest Greek temples date back to about 666 B. C., but they have every mark of being the last of a long series. It is the same with the old Egyptian temples. The earliest examples which remain are obviously a very late product. They also are the last members of a series, the early examples of which have disappeared. So it is here. For two hundred and fifty years after the Hegira the history of Mohammedan architecture is a blank, and what happened can only be guessed. The earliest Egyptian monument which still exists undamaged is the Mosque of Toulun, built in the year 876. (Plate III.)

The Arabs themselves, at least in the beginning, seem to have had little relish for the arts of design, and the development of Mohammedan architecture is apparently due, in the main, to a people of another race. These were the Turks. They, like the Arabs, were a nomadic people, with no art and with even less literature, but they had, as they have shown in many fields, a strenuous disposition, — they were of a masterful turn of mind; they had a sincere appreciation of what was good in the art of design and they had a passion for building. The history of Mohammedan architecture is chiefly the history not of the Arabs' work, nor of work done for the Arabs, but of the work done for the Turks by the races whom they conquered. They made their appearance in Egypt in various guise, as slaves, as mercenaries, as allies, or as conquerors, and in whatever character they appeared they manifested the tyrannical disposition which enabled them to control the government, and the appreciation of art which turns a potentate into a patron. Both ran in their blood.

What is called Saracenic architecture is then, even in Egypt, not that of the Saracens, but that which was patronized by the Turks. Here, as afterwards in Constantinople and in India, they employed native workmen to build and adorn their monu-

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ments. But who were these artists? If we knew the history of the first two hundred and fifty years we should be better able to answer this question, but the artists employed in Egypt were apparently the ancient inhabitants of the country, the Copts. The derivation of this name is somewhat disputed. It may come from the town of Coptos, an important Christian city under the Romans. But Copt seems to be "Gypt"; at any rate, the Copts were the old Egyptians. There is another derivation based on the fact that they were Jacobites; "c" "b" "t" spells Copt, very nearly. There was an early Christian father, a Syrian, named Jacob Bar-Dai. He and his followers, called Jacobites, were denounced as heretics by the Council of Calcedon in 415, but the Egyptian Christians held to the Jacobite doctrine, and may possibly have got their name from it. This doctrine, which thus had an oriental rather than a Greek origin, just suited the mystical turn of the Egyptian mind. It held that it was absolutely impossible that in the person of the Saviour the human and the divine should have been united, for the divine cannot possibly have anything in common with the human. This is what is called the Monophysite doctrine,—the theory of only one nature. There are still 600,000 Copts in Egypt who to this day profess the Monophysite heresy. Their religious services are still conducted in the Coptic language, which, however, they no more understand than do most Catholics understand the Latin prayers of their church. If you enter a Coptic church you hear the Coptic language and listen to the last echoes of the ancient Egyptian tongue.

Now these Copts were the artisans and artists whom the Arabians, and afterwards the Turks, employed. It is recorded that the first mosque at Mecca was built by Copts who were captured in the Red Sea, with all their building materials, while on their way to build a church in Abysinnia. By the time of Toulun, in the ninth century, the new style was apparently so perfected that it only needed encouragement to produce works of great splendor. This Toulun was a Turk, one of a band of mercenaries who had been brought from Bagdad. He rose from being steward of the palace to the position of supreme ruler,

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very much as had happened in France, a hundred years before, when Pepin, Mayor of the Palace, founded the Carlovingian dynasty. Toulun obtained complete control of all Egypt, established the dynasty of the Toulunides and built himself a new mosque at Fostat. Like the mosque of Amrou, which it resembles in plan, it consists mainly of a large court much like the courts of the old Egyptian temples at Luxor and Edfou. (Plate I.)

This central court was called the *Sahn*; the arcades around it, the *Liwan*; the niche showing the direction of Mecca, the *Mihrab* or *Kibleh*; the pulpit, alongside, the *Mimber*; the desk, holding the Koran, the *Kursi*; the gallery or raised platform from which the clerk repeated the lessons was the *Dikkeh*; and the fountain in the middle of the Sahn, the *Sebil*. These features were in time much modified, and some finally disappeared. Under the Baharite Mamelukes the Sahn was much contracted, and the arcades of the Liwan were replaced by great vaulted niches. Finally, in Constantinople the Ottoman Turks covered the Sahn or central court with a dome. Some of the latest and smallest Egyptian mosques, such as the beautiful Bordeni mosque, had only the niche and the pulpit, the Mihrab and the Mimber.

The story told of the mosque of Toulun is that it had been the habit to get columns by pulling down Coptic churches, but that the Coptic architect whom the conqueror wanted to employ refused to have any part in such desecration, and said that if he could have a free hand he would build the finest mosque in the world and not use a single column. This is the mosque of Toulun.

The descendants of Toulun reigned one hundred years. Meanwhile, the heretical Shiites had established themselves in power at Tunis and in the year 970 their general, named Moezz, conquered Egypt and established the dynasty of the Fatimites. This is about the only appearance of the Fatimites in history, except in Persia. These took possession of Fostat and built near by the new town of Cairo. (Plate I.) This was at first a sort of royal suburb. The story here is that they had

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consulted the astrologers and had strung a string of bells which was to be rung at the propitious moment, giving notice to the workmen to begin work simultaneously. Unfortunately, while they were waiting for their signal a raven passing by lighted on the string, the bells rang and the work was begun, when to their consternation the people found that the planet Mars was just in the ascendant. Mars was considered a planet of evil, but the officers in charge, with much presence of mind, proclaimed that the omen was a happy one, and that the town should be called the victorious. It thus received the name El Kahira, the victorious, from which the modern names of "Le Caire" and "Cairo" are derived.

The years of the Fatimites were among the most splendid in history. Their Cairo was the city of the Arabian Nights. The contemporary and apparently authentic accounts of their display of wealth are almost beyond belief. What remains at this day are only some beautiful private houses and some half ruined mosques, of which the largest is the mosque El Ashar, "the Resplendent" (Plate IV), now used for the University, and the mosque, built by the fanatical Sultan El Hakim, now occupied by the Arabic Museum.

Meanwhile, the Turks were again in evidence, this time as allies. The Seljukian Turks had established themselves in Syria with headquarters at Damascus. The Crusaders undertook to conquer Egypt, and the Fatimite Sultan made an alliance with the Turks at Damascus, who sent Saladin to his assistance, who burned the city of Fostat lest it should fall into the hands of the Crusaders. Its remains are now known as Old Cairo. The modern Cairo consists of the Fatimite suburb El Kahira and the district called Misr, which lies between El Kahira and a Citadel which Saladin built towards the south and by the aid of which, like a Roman of old, he held in subjection the people he had rescued. (Plate I.) Thus the dynasty of Saladin and his descendants replaced the Fatimites. It is called the dynasty of the Ayoubites, from his father, a Seljukian Turk of Damascus named Ayoub. The principal architectural monument of Saladin is this fortress. (Plate IX.)

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When, in the year 1250, the Mongols conquered Bagdad, the Abbasside caliphs, as has been said, fled to Egypt and nominally resumed the sway. But they had no political power. The government was seized by successive dynasties of slaves, or Mamelukes. Here again the Turks are in the ascendant, for the first Mamelukes were Turkish. We have met the Turks, first as mercenaries, then as grasping allies. Now they appear as slaves and the Mameluke Sultans of the first dynasty reigned for more than two hundred years. They were called Baharites, being quartered near the Bahr, or river. Two of the most famous mosques were built by them, the Mosque of Sultan Kalahoun (Plate V) and the Mosque of Sultan Hassan (Plate VI). The earlier mosques had been quite plain on the outside, but from the time of the Baharite Mamelukes their buildings began to take on some exterior architectural treatment.

The Mosque of Kalahoun is not merely a mosque. It is also a Muristan, or hospital, and large buildings are connected with it. The Mosque of Sultan Hassan also is really a Medresa, or school, a building ten stories high, attached to which is the tomb of the founder. This is covered by a dome, a construction which was originally used in Egypt only for tombs.

The Turkish Mamelukes were succeeded by a dynasty of Circassian slaves, who are known as the Borghite Mamelukes, or those from the Fort. They built the Mosque of Moayed near the southern gate of the city, much after the plan of the Mosque of Toulun, and splendidly adorned it with marbles. (Plate VIII.) They built also the so-called Tombs of the Caliphs outside the eastern gate, of which the most noticeable are the mosque-tombs of Barqouq (Plate VII) and of Kait Bey (Plate IX). A similar collection of tombs, mostly anonymous, beyond the citadel of Saladin on the south, is called, with better reason, the Tombs of the Mamelukes.

Finally, the Turks appeared in Egypt as conquerors. The Ottomans took Constantinople in 1453, and early in the next century conquered Egypt but continued the Mamelukes in power. Their principal architectural works are the mosques at Broussa in Bithynia and those built in Constantinople in imi-

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tation of the church of St. Sophia. About a hundred years ago the Egyptian ruler Mehemet Ali murdered all the Mamelukes within the Citadel of Saladin and built there a mosque after the Constantinople pattern. (Plate IX.)

Meanwhile, although the Mameluke governors had not done very much building in Cairo, two of their mosques are of special interest, — the mosque at Boulak, a suburb of Cairo near the river (Plate X), and the little Bordeni mosque, near the Citadel (Plate X). The Boulak mosque, and a copy of it within the precincts of the University, is covered with a dome, but it is in plan and arrangement entirely unlike the domed mosques at Constantinople, and both in design and in architectural treatment it is one of the most original and charming of buildings. The Bordeni mosque, built about seventy years later, is very beautiful in detail, but without structural features. It is merely an oblong room with a niche and a pulpit, the Mihrab and Mimber, but no Sahn; that is to say, no court.

II.

But the quality of Mohammedan architecture lies not wholly in the disposition of the plans and the composition of the masses within and without. The novelty, ingenuity and elegance of the structural and decorative details are equally admirable, and some of them present peculiarities of unusual interest.

The most conspicuous of these is the so-called honeycomb, or stalactite, work, a singular device which is used on the under-side of all sorts of projections, almost to the exclusion of mouldings. Capitals, cornices, string-courses, brackets, arches and vaults, domes and the pendentives that support them, are entirely composed of little niches piled one above another in an endless variety of fantastic combinations. Sometimes these are rectilinear, and resemble a broken honeycomb; sometimes they are bounded by curved surfaces. It is not difficult to devise theories as to the origin of this unique feature. But since for the first two hundred and fifty years after the Hegira we have no Mohammedan buildings, and in the oldest that now

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survive the distinctive features of the style are, as has been said, already fully formed, all hypotheses in regard to its source are equally difficult of verification. Everybody is free to choose for himself the one that seems to him to be the most reasonable.

1. From a strictly historical point of view, the most interesting theory is that which finds the first suggestion of stalactites in what are apparently the earliest known Mohammedan buildings, the so-called tombs of Zobeide and of Ezekiel, near Bagdad, built by Haroun al Raschid about the year 810. These tombs are roofed over by successive ranges of overhanging brick niches, in ten or twelve stories, each niche being supported upon corbels, which in the tomb of Zobeide occupy the spandrels between the niches; in the tomb of Ezekiel, which seems to be a later development, they rest upon their summits. Both treatments are to be found in stalactite work. The interior of these tombs, if covered with a coat of stucco, would present very much the aspect of a stalactite dome. (Plate XI.)

2. One theory finds in stalactites an imitation in miniature of a form of domical construction still used in Persia. These domes are formed by a series of interlacing arches which leave between them diamond shaped panels, which in many examples are scooped out in the form of shells. The effect is not unlike some of the larger honeycomb domes of Egypt, one of which is illustrated in Plate XIII. But no historical connection between the two has been clearly made out.

For these suggestions I am indebted to a paper read before the Royal Institute of British Architects by my friend Mr. Spiers in April, 1888.

3. One might, however, if he were to disregard these intimations, fancy that the pile of niches, or small domes, which constitute the simplest and presumably the earliest variety of stalactite work, were an imitation, *in petto*, of the pile of great half-domes and niches to be found at the eastern end of the church of St. Sophia at Constantinople. (Plate XI.)

The imitation upon a small scale, for solely decorative purposes, of large constructive features, — such as columns, capitals and entablatures, arches and arcades, piers, brackets and

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pediments, — is of frequent occurrence in all styles of architecture, and for a century before the Hegira these great niches and the spherical pendentives upon which they rest had been the wonder of the world as much for their grace and beauty as for their dignity and boldness. What more likely, then, than that they should be decoratively reproduced on a smaller scale? But in point of fact this seems not to have happened, even in the countries most directly under the influence of Byzantine art. It was not likely to happen in Egypt, for the Copts, in their art as well as in their religion, sedulously repelled all Greek influences, and the Byzantine dome with its pendentives played in fact little part in Mohammedan architecture until, a thousand years later, Constantinople was taken by the Turks. In Egypt, as afterwards in Persia and Hindostan, the transition from a square plan below to a circular dome above, or from a rectangular recess to the semicircular niche which covers it, is generally made by throwing arches across the corners, thus bringing the square to an octagon. The spandrels between the arches are not occupied by hollow spherical surfaces, as at St. Sophia, but are sometimes left plain, and sometimes filled with great polygonal or even star-shaped brackets. It is in this feature, not in the Byzantine half-domes, that we may perhaps find the prototypes of the little stalactite niches and of the corbels sometimes which support them. Examples of this are shown in Plate XI.

That from the Fayoum shows the inside of a dome of cut stone which passes from the square below to the circle above by way of eight-sided and sixteen-sided polygons. In the smaller one from the Tombs of the Caliphs, the arch thrown across the corner of the square is filled in with four rows of little niches which, with the broken spandrels between them, almost exactly reproduce in miniature the larger construction above. In this example the overhanging piers between the upper niches do not come in line with the piers below, the re-entering angle between the spandrels being ill-calculated to support them, but, as in the Tomb of Ezekiel, they rest upon the crowns of the niches, which are thrown forward to receive them.

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In the larger one, however, of the niches form Cairo doorways, the spandrel is occupied with an octagonal, or even star-shaped, corbel, which also is reproduced in miniature between the niches of the stalactite work which fills the upper arch, to support the little piers that separate the niches. These may well have been suggested by the large ones below. The smaller niche also shows these star-shaped corbels.

It is to be noticed that these great corbels closely resemble the inverted polygonal and star-shaped pyramids which occur in some later developments of Gothic groining, though they lack the ribs which are the characteristic element in Gothic vaulting. The cusped and pointed arches, also, remind one of mediæval work. But this elaborate and beautiful development of Saracenic groining seems, curiously enough, to have been confined to these doorways, and not to have been used for the vaulting of interiors, which was probably considered too bold an undertaking.

The larger example from the Tombs of the Caliphs shows how rows of niches were made to take the shape and exactly fulfil the function of a Byzantine pendentive.

It was, moreover, a peculiarity of the Saracenic builders that, with a singular neglect of constructive propriety in design, they habitually left the arches which were thus thrown across the corners hanging in the air, without any supporting corbels at all, as may be seen in the example from the Fayoum. The constant recurrence of this curious treatment in the miniature stalactite niches, as is exemplified in the other domes, would seem to confirm the hypothesis that they owe their origin to the imitation of larger constructive members.

4. But it is hardly necessary to go so far afield as Persia or Bagdad, or even to suppose that stalactite work is the imitation in miniature of larger constructions nearer home, since the methods of brick building now used in Egypt offer forms closely analogous to them and of the same diminutive scale. The brick corbels habitually employed in modern construction look very much like the angular, or honeycomb, variety of stalactites, and they need only to be covered with a coat of plaster,

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as walls in Egypt have always been covered, to produce what the Spaniards call the egg-shell variety, the plaster filling up and rounding off the sharpness of the angles. The four figures on the bottom of Plate XI illustrate this suggestion.

How much credence should be given to either of these hypotheses must depend upon the support afforded them by the facts of history, data which seem to be at present inaccessible. Without such support the most plausible and self-consistent theories are of little worth. But these inquiries are after all merely a matter of curiosity; for what gives vogue to manners and customs is the vital thing, not what starts them. The women now march off in a body at the end of a dinner, deserting the men, in order that each party may, for a change, consort for a while with their own kind, not, as in the origin of the custom, because the society of gentlemen in their cups is liable to become uncongenial to ladies. So here, and in the contemporary Gothic architecture, the important question is, not what first suggested stalactites and pointed arches, but why these varieties, or species, once planted, suddenly overran their respective fields, to the exclusion and suppression of other forms, with all the tyranny of a dominant fashion.

It is not so important to know what was the first hint of stalactites, as to know why the suggestion was taken up and developed with so much zeal. This seems to have been due to a predilection for geometrical ornament, and this, in turn, to have been due to the mystical turn of mind of the later Egyptians. A repugnance to the use of the human form, and even of the forms of animal and vegetable nature, was an eminently Coptic prepossession. The Mohammedan precept forbidding painting and sculpture is not found in the Koran, but the successors of Mahomet, in their exposition of the Koran, seem to have adopted the idea from the Copts, wishing probably to make converts among them. The Koran says one shall not *worship* the image of anything created, but the Copts went further and objected to making any representations of any created thing. This is now the teaching of the orthodox Mohammedans in nearly the entire Mohammedan world, although the

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heretical Fatimites, both during their ascendancy in Cairo and nowadays in Persia, have largely rejected it.

The Copts were ascetics. It was in the Egyptian mountains that the solitary life of the first hermits was established. In their distrust of the natural world and its beguiling beauties they even went so far as to consider that curved lines were of the evil one. No right minded person would tolerate anything but right lines, and in their architecture the Coptic builders even revived the rectilinear arches which are found in the earliest Egyptian pyramids. In the decorative work of the Mohammedans, accordingly, the lines are nearly all straight and the few curved lines which are employed represent only geometrical figures. These predispositions had already been conspicuously manifested in the time of the Romans, who called the mosaics which were made up of square and triangular tesserae, carefully shaped and fitted, by the name of *Opus Alexandrinum*. Extraordinary skill and invention are shown also in the construction of interlacing patterns, and in the inlaying of marbles or other stones, often making the inlaid figure and the background of the same shape but reversed. The skill thus fostered found abundant exercise in developing all the possibilities of stalactite work, which by the time of its first appearance in existing buildings had attained an intricacy and complexity which well nigh baffles comprehension, and as we have seen, makes it almost impossible to tell in what structural suggestions it may have originated. In despair of finding any rational explanations, some writers have even turned to symbolism and fancied that the little niches of which the work is made up of are repetitions on a smaller scale of the Mihrab, or sacred niche, which in every mosque points the worshipper's face towards Mecca.

In view of all this we may not be far wrong if we take the view that, these accumulations of hollow niches having once commended themselves to the taste of the time, the same patient ingenuity and exuberant fancy which led to the elaboration of geometrical patterns in the flat, found in the problems of solid geometry which these studies presented, an equally congenial field. And just as in their patterns of wood and marble

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inlays and interlacings, forms suggested by weaving and brick-laying, they adhered to the straight lines and circles which geometry affords, so here they enriched their cylinders, hemispheres, and parallelopipedons by adding to them whatever suggestions were offered by the groinings and corbellings of the stone-mason and brick-layer, thus giving a new interest to their work. One may as well suppose these to be the last steps in the process of development as the first.

A less well-known example of their geometrical ingenuity is their solution of the problem of architecturally squaring the circle, so to speak; that is, of connecting a square figure with a circular one. This problem found its most famous solution in the pendentive dome of St. Sophia. The transition is there made by means of spherical triangles, and the Romanesque architects adopted the same device not only in their domes but, on a smaller scale, in making the transition from a round shaft to a square abacus or plinth, in the so-called "cushion" capitals and bases. But the geometrical Copts hit upon another device which was exceptionally clever and which better suited their rectilinear turn of mind. Knowing that between any three points a plane triangular surface may be drawn, they took any number of points on the circle and from these points passed zig-zag lines connecting them with an equal number of points upon the square. The surface connecting the square and the circle was thus divided into plane triangles, each of which was sometimes broken up into three smaller triangles by depressing a point in its centre; and these again sometimes given a similar treatment. Examples of this device are found in the base of the columns which flank the great doorway of the Mosque of Sultan Hassan, and in the base of the minarets of the mosque at Boulak and of the Suleimanieh at Constantinople. Several capitals in Cairo and those in the porch of the Mosque of Rustem Pasha, also in Constantinople, exemplify the same method. My friend Mr. Partridge has furnished me with a curious example of the same thing from the church of St. Remi at Rheims. (Plate XII).

The same device is employed on the outside of the Tombs of

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the Caliphs and of the Mamelukes at Cairo, to pass from the square walls below to the base of the circular or polygonal dome above. An elaborate series of large mouldings, like a gigantic chamfer-stop, was also adopted in these buildings to give to the exterior surface of the pendentives an appropriate architectural treatment, a problem which both the Gothic and the Renaissance architects have constantly evaded. (Plate XII.)

The most interesting application of this expedient is to be found, however, not in Constantinople or in Cairo, but at Broussa, where the Ottoman Turks established themselves, as has been said, before crossing into Europe. In the domes of several of the mosques, and in a great niche, a half-dome, at the entrance to one of them, the transition from the square below to the circle above is effected in this manner. (Plate XII.) One of the examples shows each of the original triangles occupied by nine smaller ones. I do not know that these buildings have yet been published, or that attention has been called to these clever geometrical constructions.

Other distinctive devices of the Mohammedans are the horseshoe arch and dome, and the domes supported upon intersecting arches which are to be found in Sicily, Spain, India, and Persia. But any discussion of these, or of the more purely decorative methods of the Mohammedans, would take more space and time than are now at our command.

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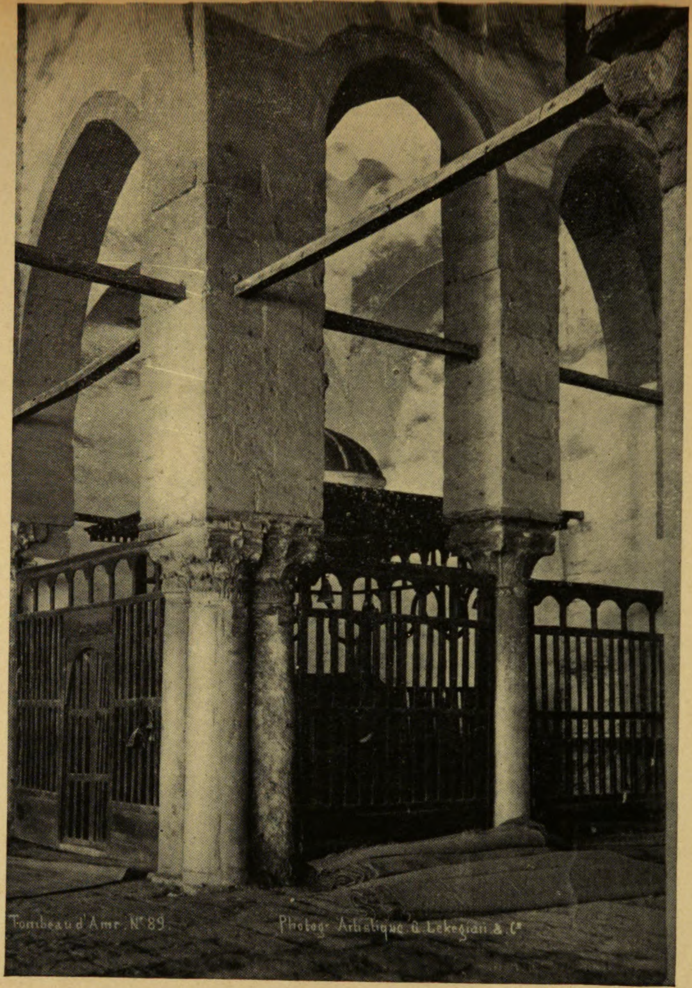

THE MOSQUE OF AMROU, A.D., 642.

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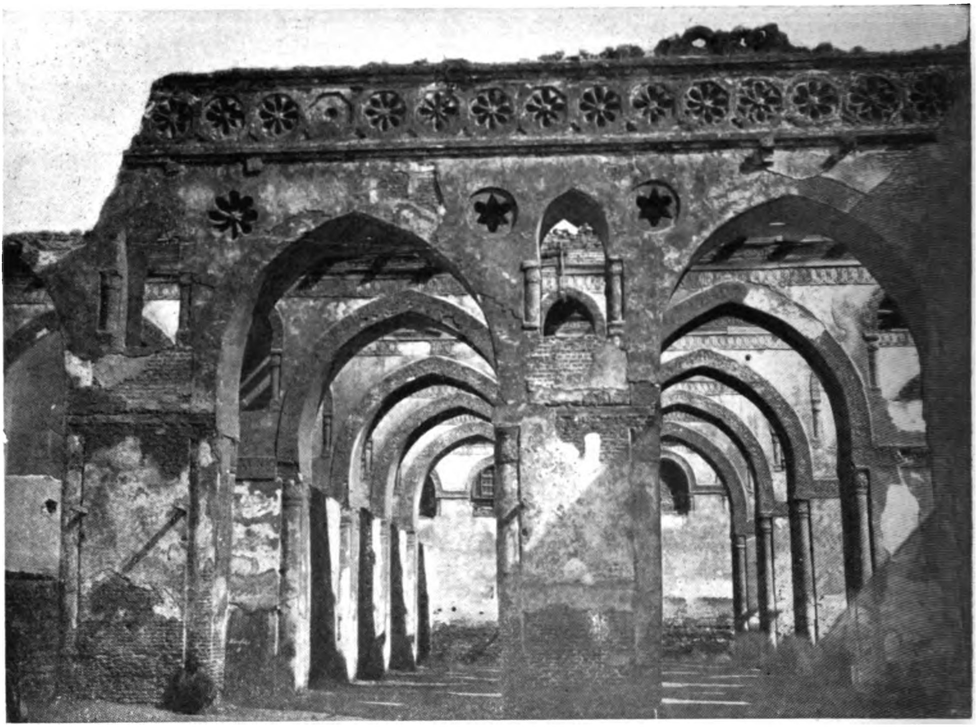
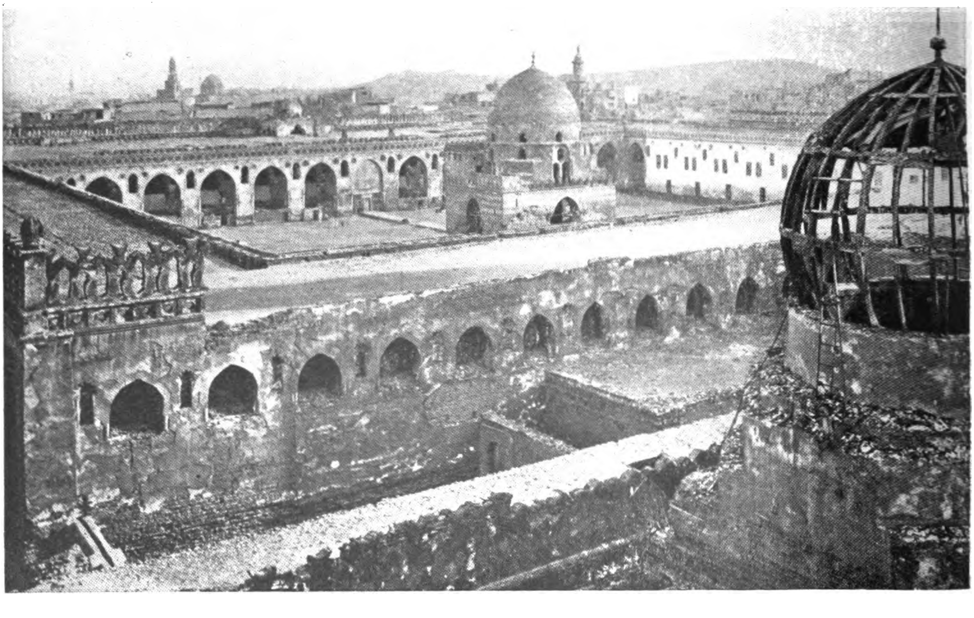
PLATE III.





THE MOSQUE OF TOULUN, A. D. 876.

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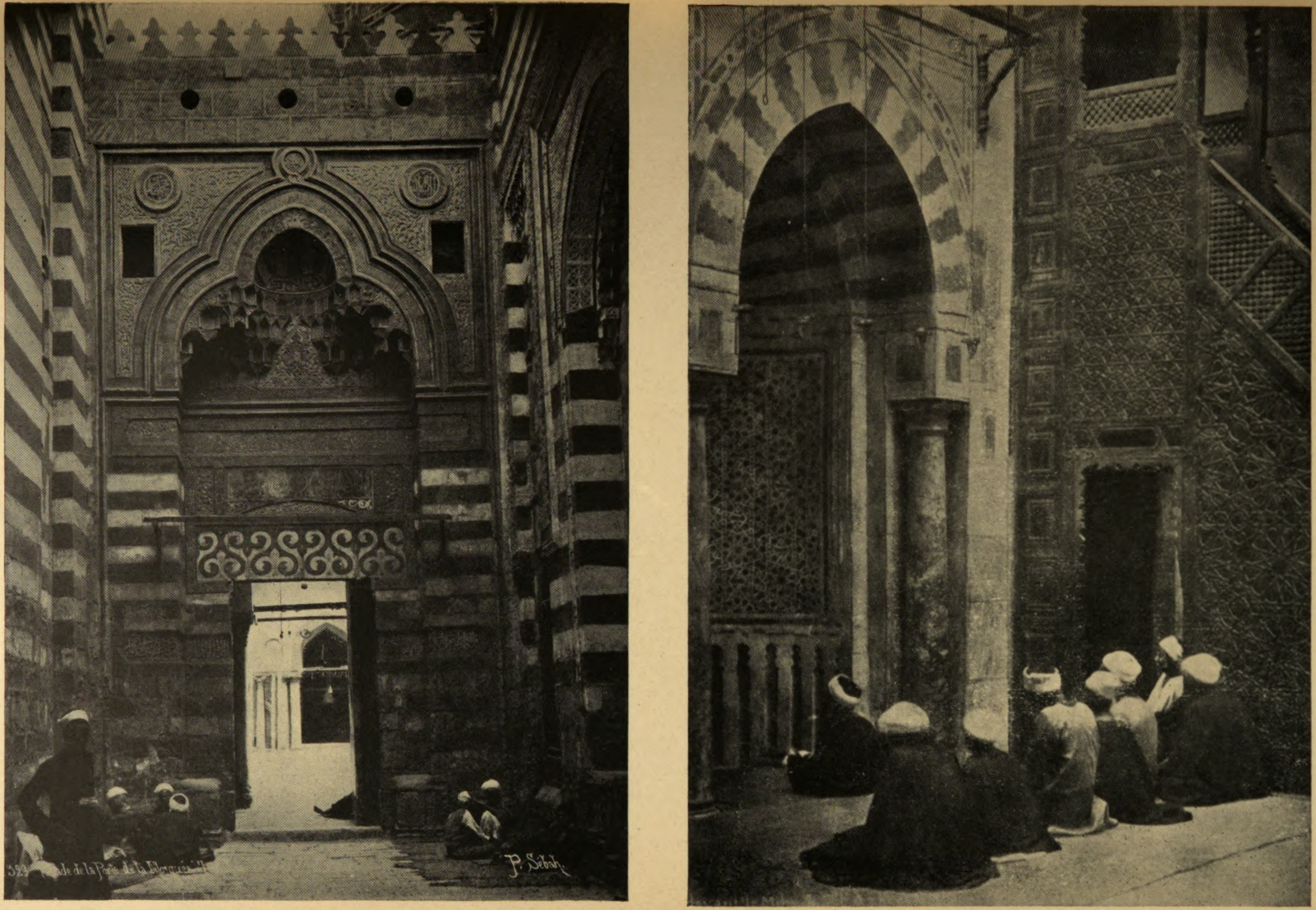

THE MOSQUE EL ASHAR (THE UNIVERSITY) A. D., 981.

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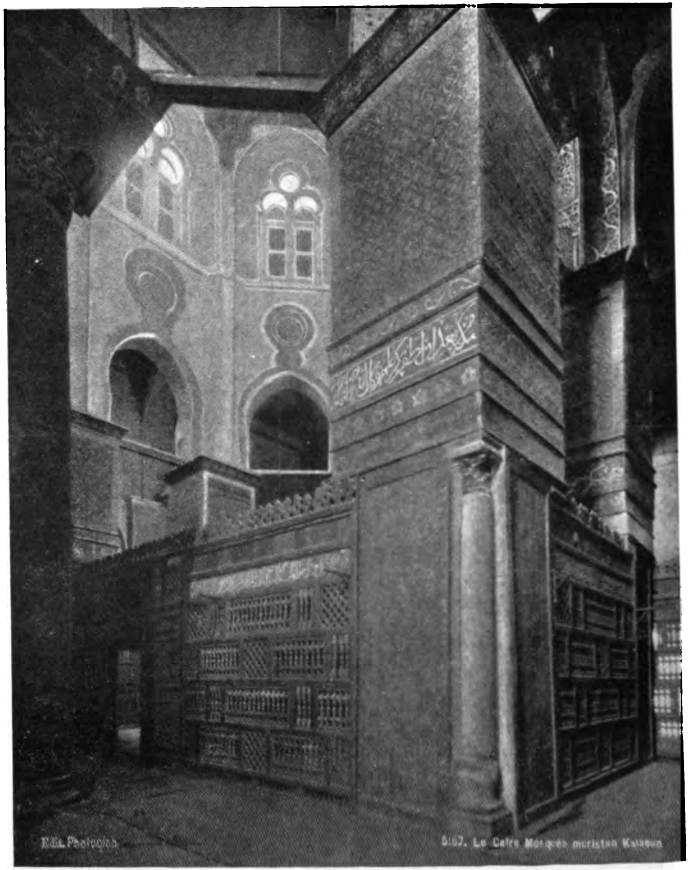

THE MOSQUE OF SULTAN KALAHOUN, A. D., 1287.

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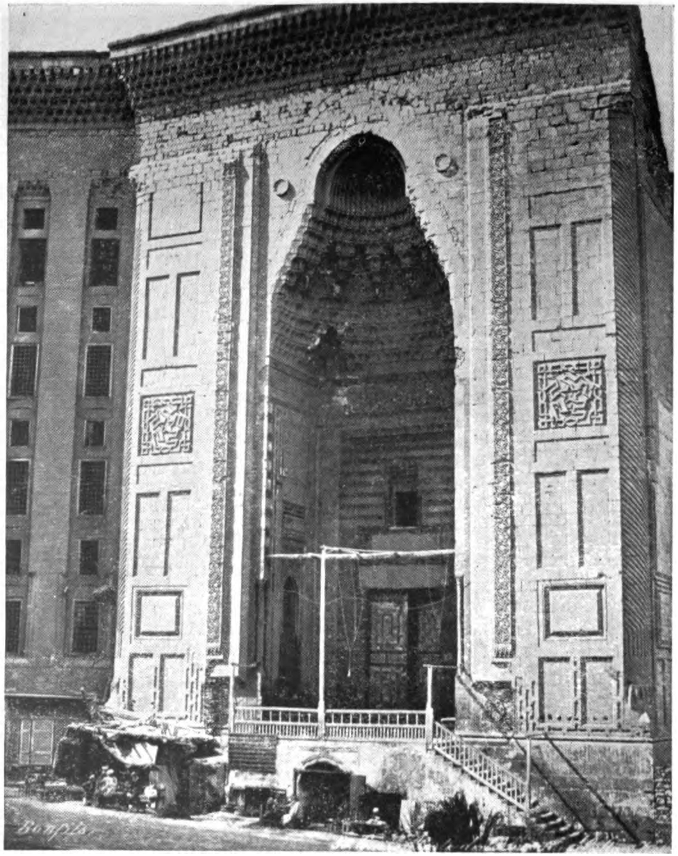
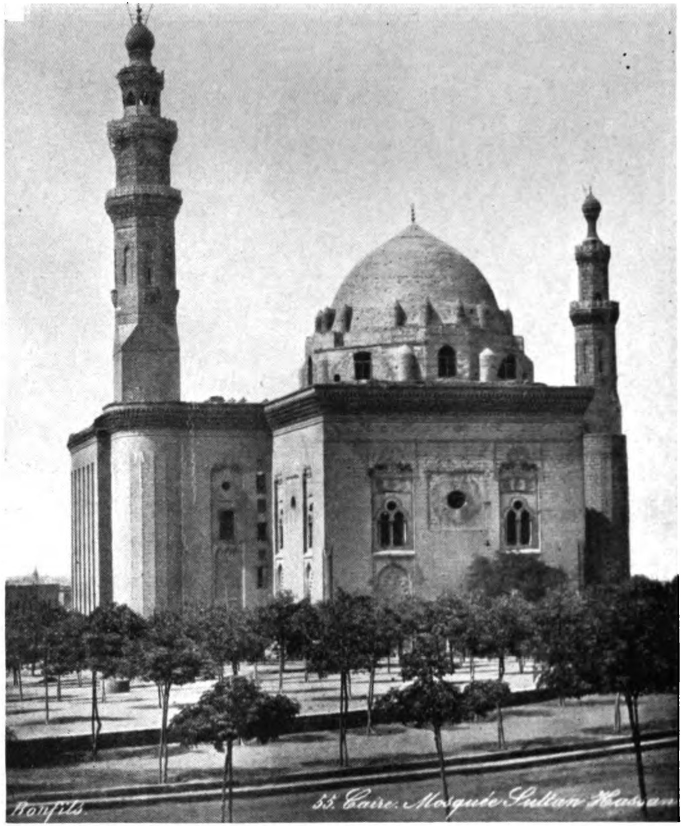
PLATE VI.





THE MOSQUE SULTAN HASSAN, A. D., 1377.

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PLATE VII.

THE MOSQUE OF BARQUOQ, A. D., 1382.

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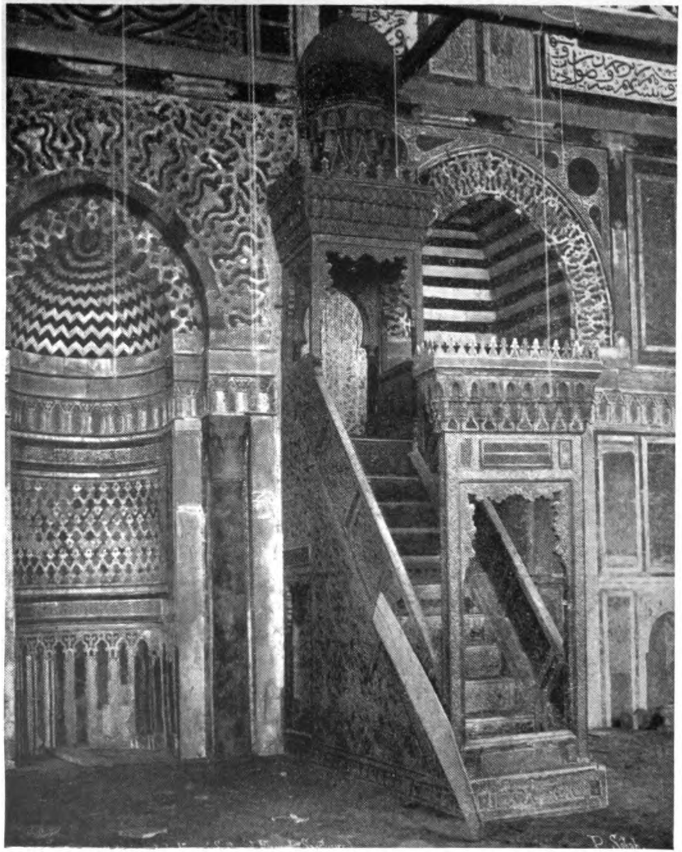
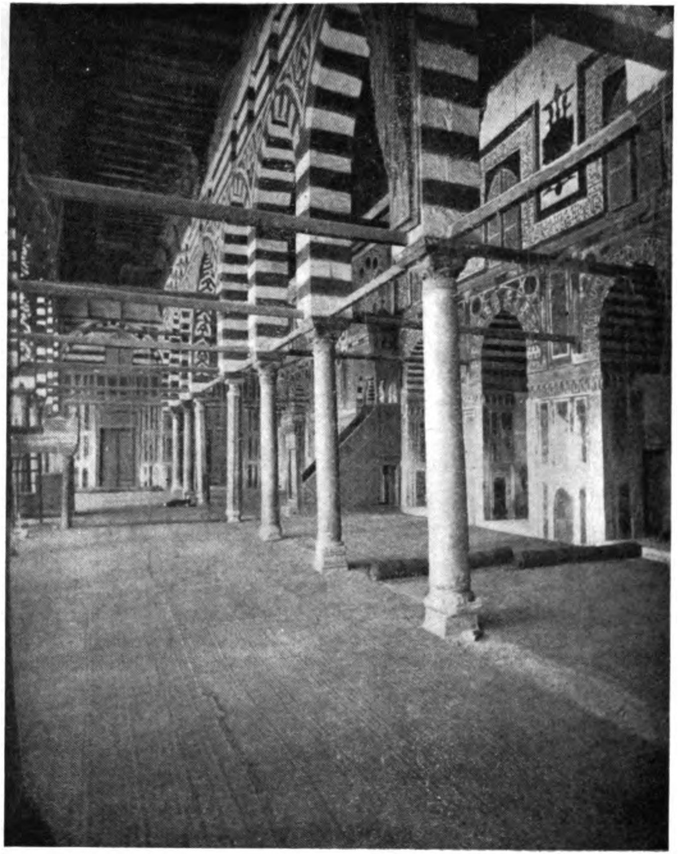
PLATE VIII.





THE MOSQUE OF MOAYED, A. D., 1412.

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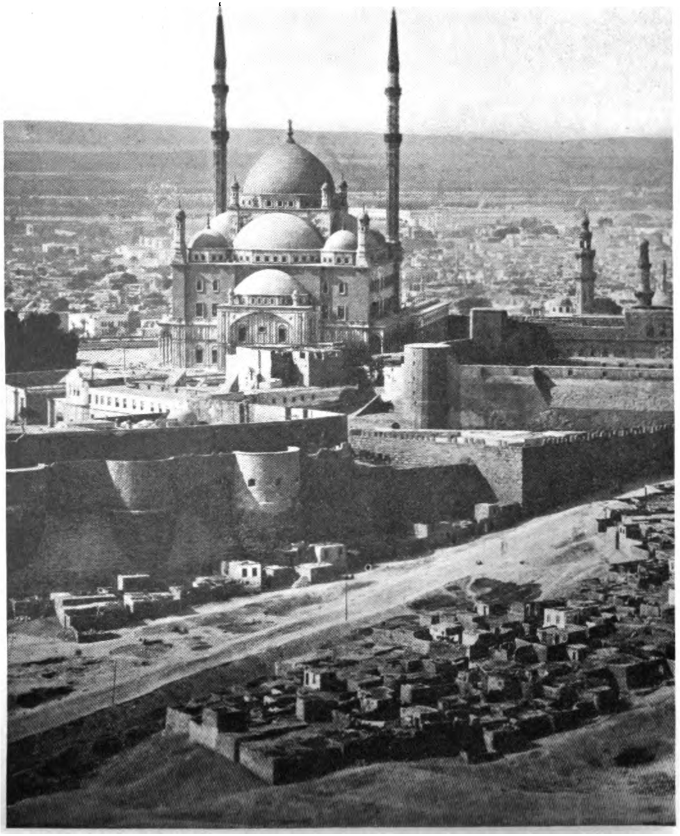

THE CITADEL OF SALADIN, A. D., 1166.
THE MOSQUE OF MEHEMET ALI, A. D., 1815.

THE MOSQUE OF KAIT-BEY, A. D., 1463.

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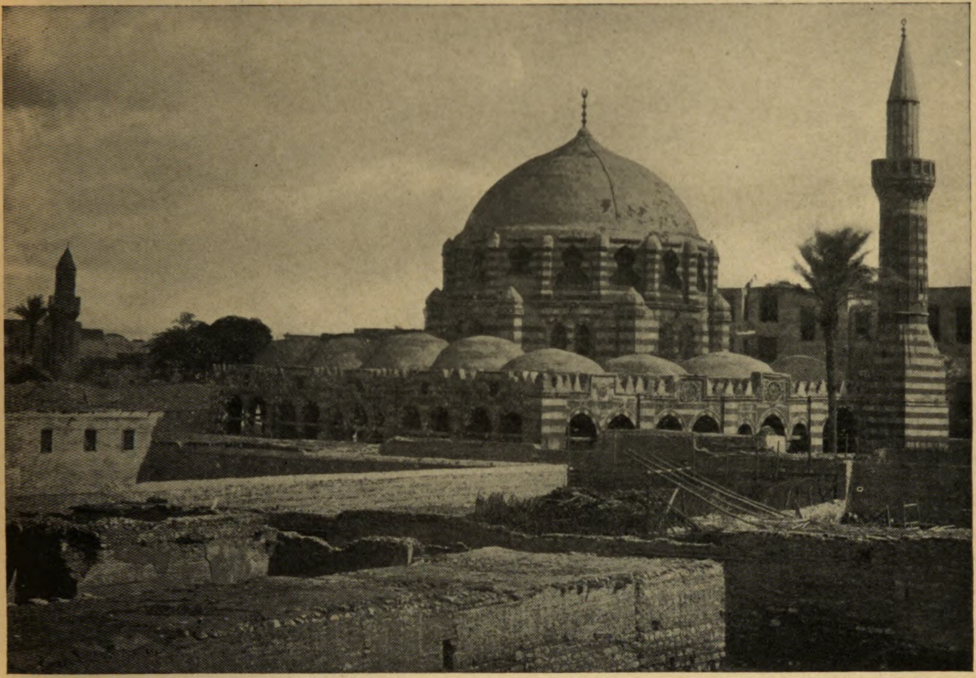
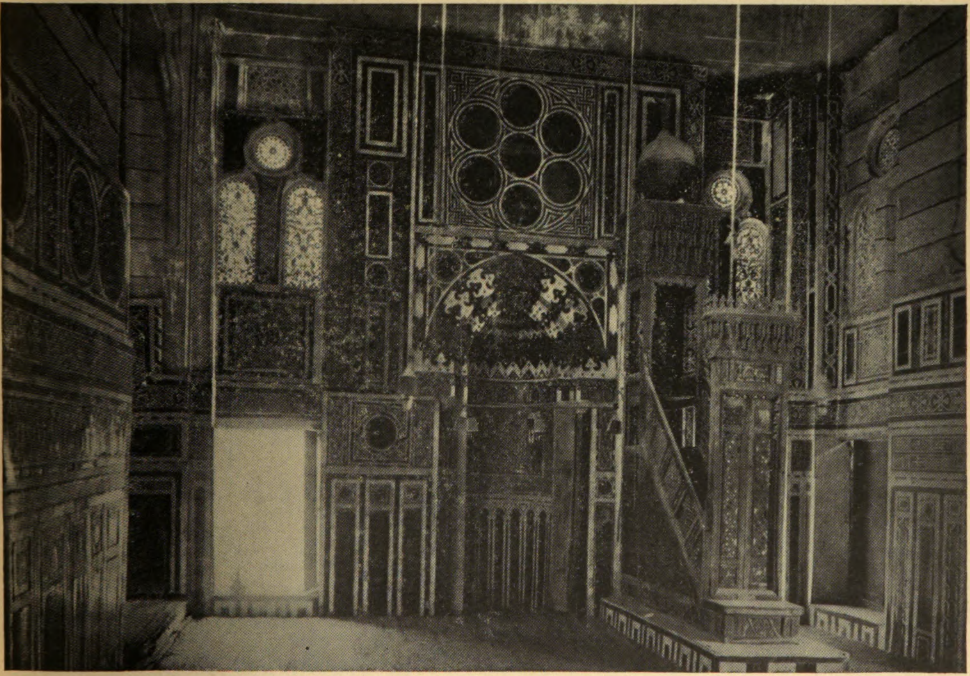


THE MOSQUE OF BOULAK, A. D., 1571.



THE BORDENI MOSQUE, A. D., 1638.

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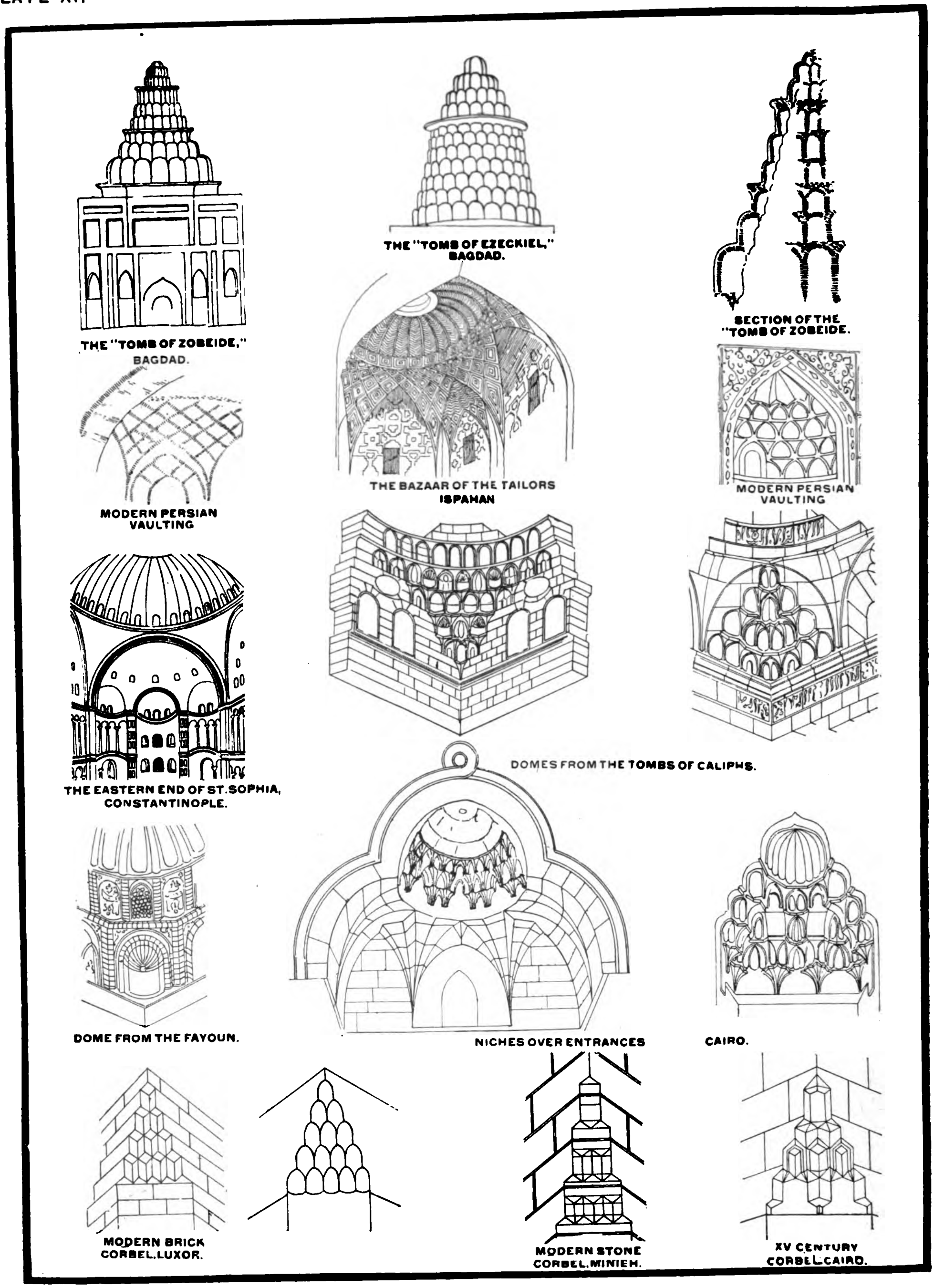
PLATE XI.



STALACTITES.

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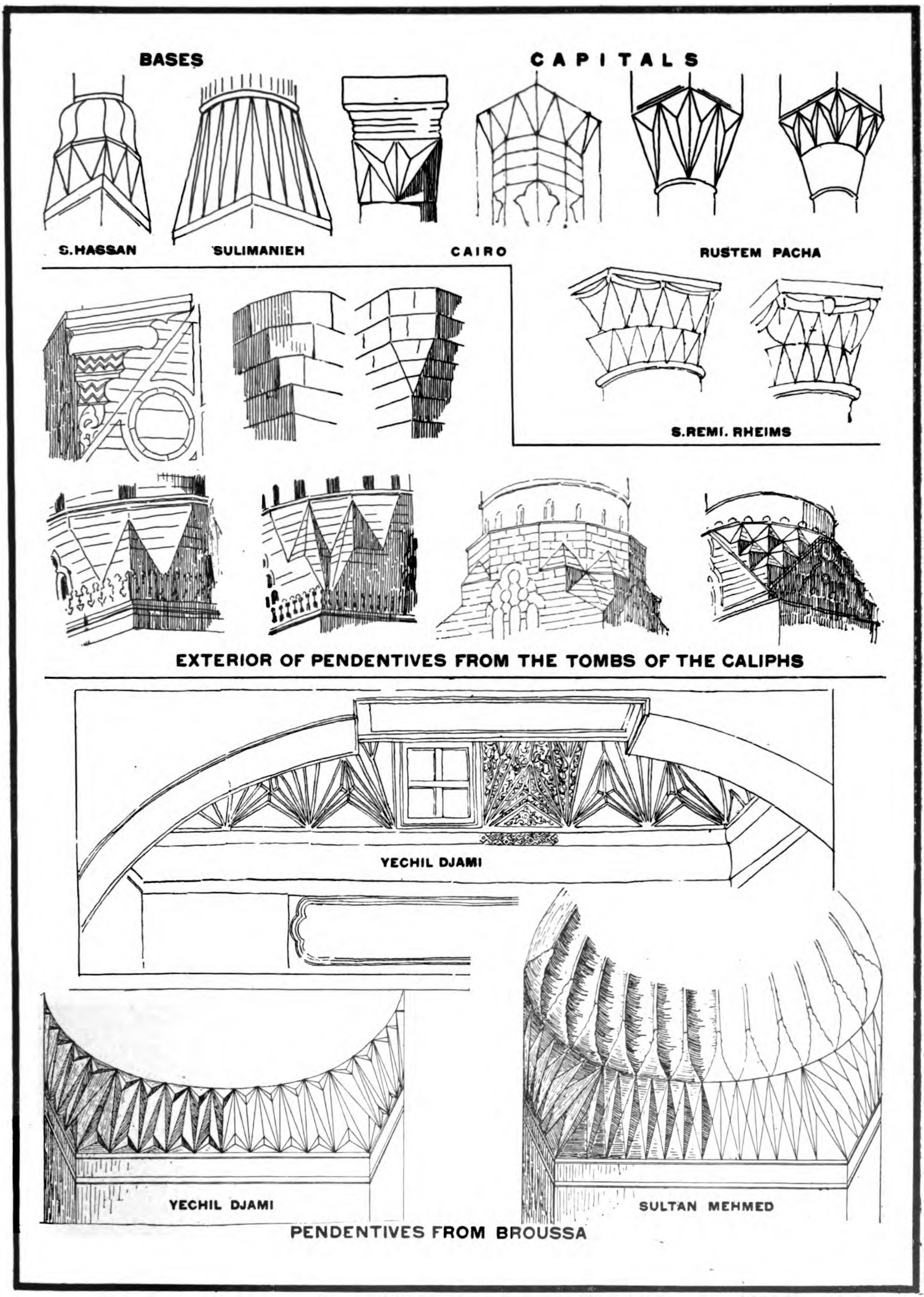

ZIGZAGS.

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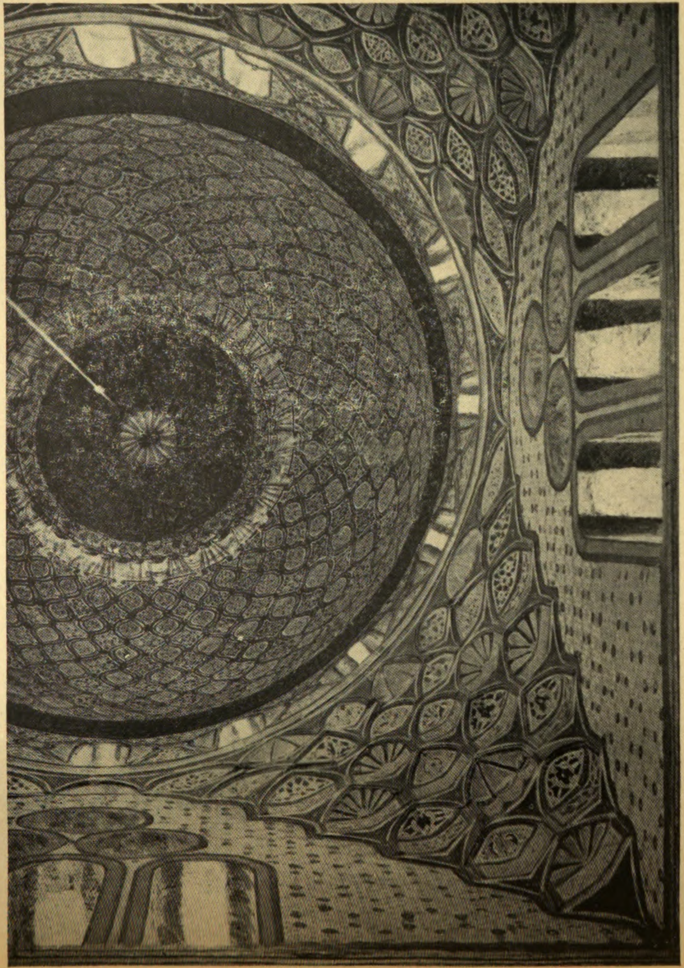
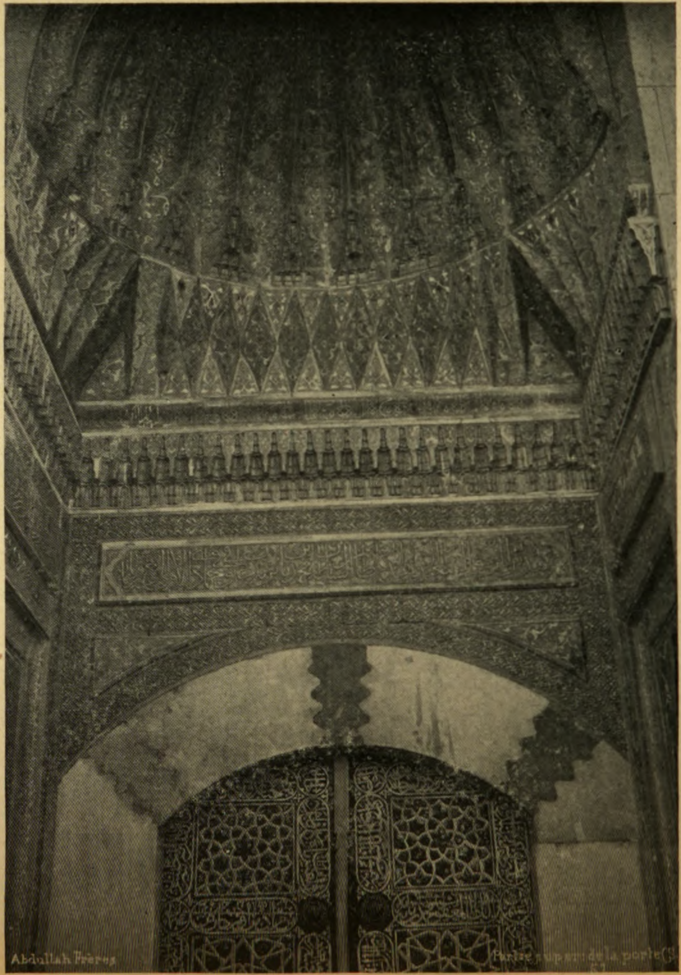
PLATE XIII.



DOME OF THE MOSQUE OF MOHAMMED BEY, CAIRO, A. D., 1774.



DOORWAY OF THE MOSQUE OF SULTAN MEHMED, BROUSSA, A. D., 1389.

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SOME NEW DATA ON THE WEIGHT OF A CROWD OF PEOPLE.*

By Lewis J. Johnson, Assistant Professor of Civil Engineering, Harvard University.

[Read before the Harvard Engineering Society, January 12, 1904.]

The weight of a crowd of people is one of the most important bits of data used by the structural engineer. It would seem to be one of the most easily determined, yet it is one on which the authorities differ widely, and one which they understate and, with few and unfamiliar exceptions, seriously understate. The engineering practice of both Europe and America accords closely with Trautwine's recommendation: †

"On bridges for turnpikes and common roads, no probable contingency could crowd people to such an extent as to weigh more than 80 lbs. per sq. ft. of floor; and this may safely be taken as the maximum load on spans of 20 or more feet. To compensate, however, for impact, we recommend to adopt 100 lbs. as the limit for crowds."

In a footnote on the same page, Mr. Trautwine cites experiments in support of the preceding, as follows:

"The engineers of the Chelsea bridge, London, *packed picked* men upon the platform of a weigh-bridge; with a result of 84 lbs. per sq. ft. Mr. Nash, architect of Buckingham Palace, *wedged* men together as closely as they could possibly stand upon an area of 20 ft. diameter; the last man being lowered down from above, among the others. Result, 120 lbs. per sq. ft."

While 80 to 100 lbs. per sq. ft. are generally accepted as the maximum for bridge-work, the city building laws of this country

* Read before the Boston Society of Civil Engineers, December 21, 1904. Printed through the courtesy of the *Journal of the Association of Engineering Societies*.

† *Civil Engineer's Pocket Book*, 18th edition, p. 726.

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specify 80 to 150 lbs. for the minimum floor loads for public assembly rooms — some cities naming the lower value, others the higher, and others still giving various intermediate values.

Why the proper assumptions for buildings have been commonly held at a higher figure than for bridges, it is not easy to say. Perhaps it is because the increased cost of the building by leaving a larger margin is relatively a less serious matter than with a bridge, and the incentive for close figuring relatively less felt. An additional factor may be that the likelihood for defective construction may have been regarded somewhat greater in the cases of buildings than with bridges. It certainly does not seem attributable to any current belief that the weight of crowds might reach 150 lbs. per sq. ft., for such a belief would certainly have been felt in bridge practice.

However this may be, the writer has been slowly coming to distrust the correctness of prevailing ideas on the whole subject, and for some months past has been making experiments in the attempt to get some first-hand information. The men at his disposal were his own students, and their patient and intelligent interest have alone made the work possible. The results up to last April were duly published * and accompanying them a series of nine extracts from writers of various countries. The writer had at that time obtained a maximum result of 156.9 lbs. per sq. ft., due to 67 men, averaging 151.5 lbs. each, in a space of 64 sq. ft. The authorities quoted in the nine extracts gave some 80, some 120 lbs. per sq. ft. as the maximum possible from a stationary crowd, one only going above 120. Mr. Stoney reported 147.4 lbs. per sq. ft. from 58 Irish laborers, averaging 145 lbs. each, packed into a space of 57 sq. ft. It was observed that the authorities, with the exception of Stoney, rarely cited any deliberately conducted experiment. The best known experiments are those quoted by Trautwine and given above. Stoney's seem to have been generally overlooked.

The result published last April was roughly verified † by Professor Spofford, of the Massachusetts Institute of Technology,

* *Engineering News*, April 14, 1904, p. 360.
† *Engineering News*, May 5, 1904, p. 426.

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and later by a German investigator in Bonn.* These gentlemen reached results of 142.5 and 144 lbs. per sq. ft., respectively, each making it clear that the limit had not been reached. In the discussion that followed, the results of Professor Kernot, of Melbourne, were recalled. He reported † 143.1 lbs. per sq. ft. as his maximum.

The writer gave the matter no further attention till within the last few weeks, when two of the foremost American structural engineers publicly expressed their belief that a load from a crowd of people in buildings in excess of 40 to 45 lbs. per sq. ft. is not exceeded in practice often enough to demand much consideration.

One of these gentlemen, Mr. C. C. Schneider, stated ‡

"A live load of 40 lbs. per sq. ft. . . . . may be considered the maximum load to be provided for as a distributed load for all floors on which crowds of people may be expected to congregate."

To allow for vibrations in the case of ballrooms, drill rooms, gymnasiums,§ etc., he recommended assuming an additional 40 lbs. per sq. ft., after stating that

"a uniform load of 40 lbs. per sq. ft. will scarcely ever be exceeded by a crowd of people."

Mr. Theodore Cooper,‖ in supporting Mr. Schneider's assumption of 40 lbs. per sq. ft. and in illustrating the rarity of a load above that figure, says:

"Most people have experienced the discomforts of a crowded Elevated Railway car when not another person can be squeezed inside of the gates. Such a crowd, numbering about 120 persons and not weighing more than 18,000 lbs., is contained in a space of about 400 sq. ft., including platforms, or 45 lbs. per sq. ft."

* *Zentralblatt der Bauverwaltung*, October 8, 1904, and *Engineering News*, November 3, 1904, p. 406.

† *Engineering News*, March 16, 1893, p. 252.

‡ *Proceedings American Society of Civil Engineers*, Vol. XXX, p. 676.

§ Ibid., p. 680.

‖ *Proceedings American Society of Civil Engineers*, November, 1904, p. 851.

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FIG. 1.—41.8 LBS. PER SQ. FT.
10 men averaging 150.6 lbs. on 36 sq. ft.)

FIG. 2.—SAME MEN AS IN FIG. 1, DIFFERENTLY SPACED.

FIG. 3.—41.8 LBS. PER SQ. FT.
(5 men, averaging 133.8 lbs., on 16 sq. ft.)

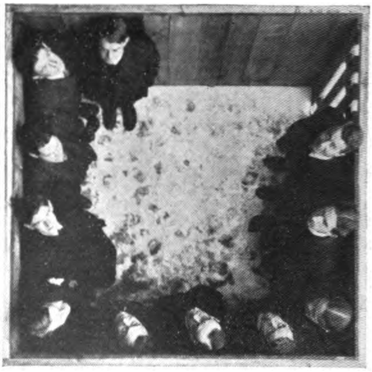

FIG. 4.—47.2 LBS. PER SQ. FT.
(11 men, averaging 154.6 lbs. on 36 sq. ft.)

FIGS. 1–4.—CROWDS WEIGHING 41.8 AND 47.2 LBS. PER SQ. FT.

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In view of these statements, the time seemed appropriate for further work on the problem, and for the sake of taking part in the discussion with Messrs. Schneider and Cooper, the writer had a series of photographs taken showing bird's-eye views of crowds at different degrees of compactness from 40 to 150 lbs. per sq. ft. These photographs are reproduced in Figs. 1 to 8, and are sufficiently explained by their titles. Special attention may be called to Figs. 1, 2, and 3 as representing crowds approximating Mr. Schneider's 40 lbs. per sq. ft. and to Fig. 4 as showing a crowd somewhat *more* compact than Mr. Cooper's Elevated Railway crowd.

In Fig. 3 the men are in an alcove four feet square. Specially light men were selected for this test for the sake of showing a specially crowded example of 40 lbs. per sq. ft. One less man, if the average were 160 lbs. each, would produce the requisite 40 lbs. with considerably less appearance of crowding.

In Fig. 7, the very high average weight (167.7 lbs. per man) is due to the fact that the crowd shown is the remnant of the crowd of Fig. 9 after twelve of the lighter men near the gate had left the box.

In all the experiments in close crowding, the men were, up to this time, left to arrange themselves.* They naturally stood entirely at random, facing in all directions.

Obviously, the next step was to see what could be reached by facing the men all one way, especially as they would be likely to be so arranged in a constriction in a street caused by a drawbridge or in standing in a crowded meeting. At the same time some care was taken to select tall men, with a view to finding out what a crowd actually might weigh. The result, to the writer's great astonishment, was on the first trial of this process 176.4 lbs. per sq. ft., due to 40 men in a space 6 ft. square. A repetition of it was made for the sake of a better photograph and somewhat better selection of men. The result (Fig. 9) was 181.3 lbs. per sq. ft., due to 40 men, averaging 163.2 lbs. each, in a space of 6 ft. square. This result is, of

* Except in Fig. 7, which, as just stated, was taken after Fig. 9.

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FIG. 5.— 83.7 LBS. PER SQ. FT.
(20 men, averaging 150.7 lbs.)

FIG. 6.— 100 LBS. PER SQ. FT.
(24 men averaging 150 lbs.)

FIG. 7.— 130.4 LBS. PER. SQ. FT.
(28 men, averaging 167.7 lbs.)

FIG. 8.— 154.2 LBS. PER SQ. FT.
(37 men, averaging 150.1 lbs.)

FIGS. 4–8.— CROWDS WEIGHING BETWEEN 80 AND 155 LBS. PER SQ. FT., OCCUPYING IN EACH CASE A SPACE OF 36 SQ. FT.

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course, an extreme, evidently to be put in the same class with the 84 lbs. and 120 lbs. in the quotation from Trautwine.

Though 181 lbs. per sq. ft. must be conceded to be an extreme, it is believed that something very close to that figure is reached over the whole drawbridge on the way from Soldier's Field to Harvard Square after one of the great football games.

Moreover, if 40 men, averaging 163 lbs. each, can stand in no serious discomfort in 36 sq. ft., it is clear that 40 men of the ordinary size of 150 lbs. each could easily do so. The result then would be 166.7 lbs. per sq. ft.

The great increase in the results of this fall over those of last spring seems to be due largely to the better economy of room from facing the men all one way and partly to the dimensions of the box being such as to work up with little waste room, both of which are conditions favoring congestion to be met in practice.

The conclusion seems irresistible that loads of 180 lbs. per sq. ft. may actually occur in exceptional cases; that 160 lbs. must frequently occur; that 140 lbs. must be common on station platforms, in corridors and many other places frequented by throngs of people; that 80 lbs. per sq ft. must be common at social gatherings in private houses. The conclusion is equally clear that the margin of safety in many existing structures designed for 80 to 100 lbs. per sq. ft. (to say nothing of 40 to 45) must be much less than has been supposed. Probably the correct inference is that the experience of many years in many lands has demonstrated that the margin has been sufficient, nevertheless. Even if that be true, it is no reason why we should remain in the dark about how much a crowd of people actually does weigh. It is only with the correct knowledge of the maximum that engineers can intelligently decide for what load any part of any structure may properly be proportioned. In thus deciding, it will not be forgotten that a crowd of people is the very last load which should be endangered by too small a margin of safety even "once in a great while."

Fig. 10 shows the box or pen in which the men gathered (after being weighed inside the building) and the scaffolding

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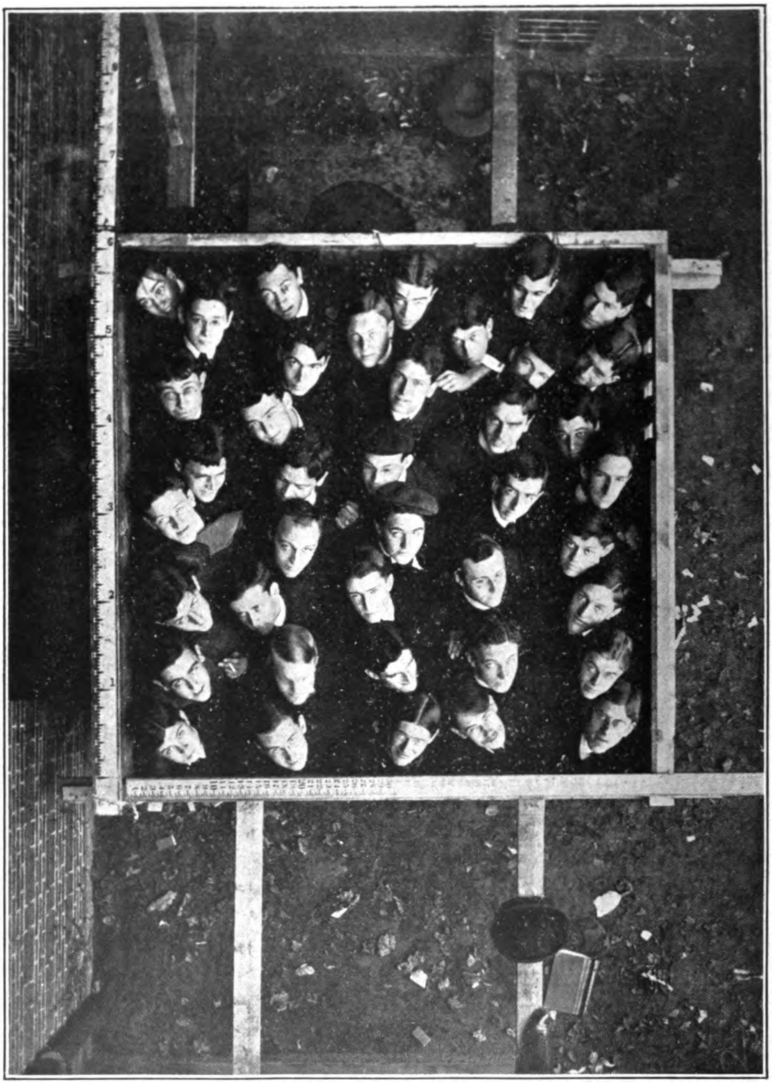

FIG. 9.— 181.3 LBS. PER SQ. FT.
(40 men, at 163.2 lbs. average, on 36 sq. ft.)

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on which the camera was mounted. The lens was pointed directly downward. The men entered the box through the gate at the right, and when the box was full the gate was closed and secured by the heavy bar shown. The braces running to

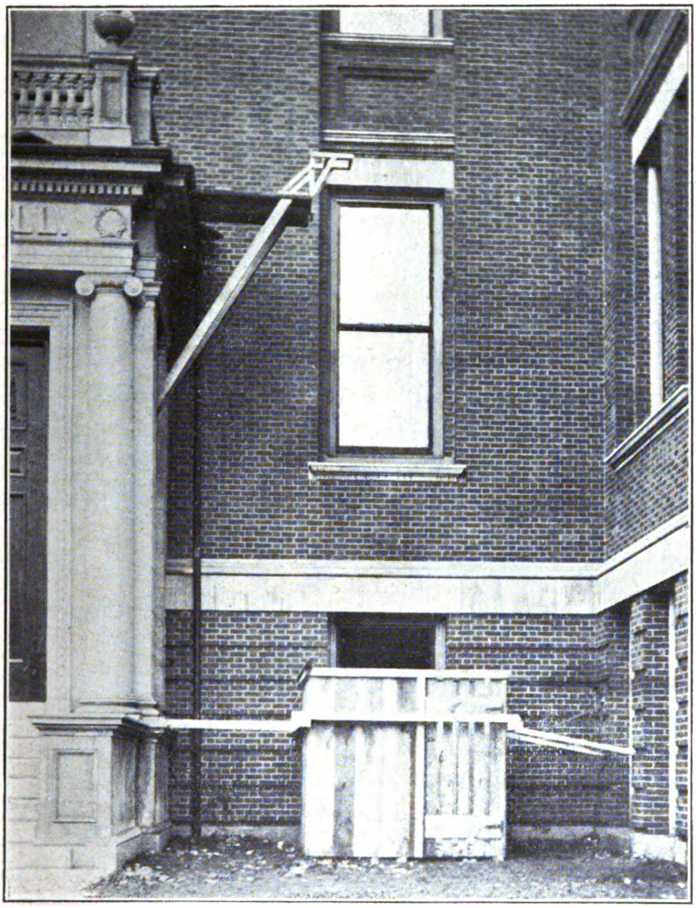

FIG. 10.—APPARATUS USED IN PHOTOGRAPHING CROWDS FOR THE DETERMINATION OF FLOOR LOADS.

the side of the porch and the wall of the building were for strengthening the box against internal pressure, which, with forty men in the inclosure, became considerable — especially

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when they took it into their heads to take a long breath simultaneously. The men were requested to look up toward the camera so as to be more easily distinguishable for counting, and so as to be identifiable as a check upon the records.

It may be interesting to add that what may be called the asymptotic value of the weight of a crowd of men must be about 218 lbs. per sq. ft. (possibly more than this rather than less with men of varying height). This figure was reached upon examination of data kindly furnished by Dr. Sargent, Director of the Harvard Gymnasium. It was obtained by dividing the weight of a man 6 ft. 3 in. tall, a former football captain, by his maximum horizontal cross-section as obtained by a planimeter. This maximum section was, of course, through the chest, including the arms. The weight of this man was 177 lbs., and maximum cross-section 117 sq. in., both quantities exclusive of clothing.

In closing, the writer takes pleasure in thanking not only the students who cheerfully submitted to the packing process, but also many colleagues and friends, particularly Professor W. S. Burke, for their general assistance, and Mr. E. E. Pettee, Assoc. M. Am. Soc. C. E., and Mr. N. E. Olds, for taking the photographs.

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TRAIN RESISTANCE.

By C. O. Mailloux.

(Continued from the January, 1905, issue.)

If, as our preceding reasoning would indicate, the tractive effort per wheel, as due to an "unclean track," decreases and tends toward zero for the rear wheels of a train, it follows that the train resistance, as usually measured, in pounds per ton, is influenced, in some inverse ratio, by the *number of wheels* in the train. Consequently we should expect that portion of the train resistance which is due to an unclean track to be lowest of all in the case of very long trains and highest of all in the case of single cars, and to be even greater for a four-wheel car than for an eight wheel car. There is reason to believe that the relatively high values found for train resistance (in lbs. per ton), on street railways can be accounted for to a great extent, if not wholly, on that hypothesis.

The total tractive effort (F_t) for a whole car or train is, of course, equal to the sum of the individual tractive efforts (F_1, F_2, F_3, etc.), for each of the wheels, thus:

$$\begin{aligned} F_t &= F_1 + F_2 + F_3 + \text{etc.} \\ &= W_1 \sin a_1 + W_2 \sin a_2 + W_3 \sin a_3 + \text{etc.}, \end{aligned}$$

where each term corresponds to a value consistent with equation (2a), $F = \frac{x}{r} W = W \sin a$, W being taken in pounds, when the values of F are wanted in lbs.

Dividing the total value (F_t) by the total *tons* of train weight, we have the corresponding *train resistance*, in pounds per ton, thus:

$$\frac{F_t}{1/2000(W_1 + W_2 + W_3 + \text{etc.})} = F_r = \text{lbs. per ton.}$$

When the weight per wheel is approximately the same for all the wheels, the same result can be obtained in a simpler way, for,

taking W = 1 ton = 2000 lbs. in (2a), the individual values, F′, F″, F‴,)etc., will now be in pounds per ton, and the train resistance, in pounds per ton, will therefore be equal to the arithmetical *mean* of these values, or

$$F_r = \frac{1}{N}\,(F' + F'' + F''' + \text{etc.})$$

where N = the total number of wheels of the train or car.

We can appreciate the importance of a clean, smooth track, if we calculate the tractive force (F), required to make a car wheel climb over "intermittent" obstructions of different sizes, for we

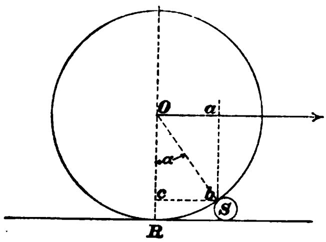

FIG. 12.

find that a very small elevation above the rail level gives a surprisingly high value for F. Using equation (3),

$$F = \frac{\sqrt{z\,(2r - z)}}{r - z}\,W$$

which is especially convenient for this purpose, (since z = the height Rc in Fig. 12), and taking W = 2000 lbs. = 1 short ton, we find, in the case of a 33 inch wheel (where r = 16.5), the following results:

HEIGHT OF OBSTRUCTION (z)	TRACTIVE FORCE PER WHEEL (F)	EFFECTIVE FICTITIOUS GRADE	
		Angle ($\beta, = \alpha$)	Per cent
0.0005 inch	15.57 lbs. per ton	0°26′46″	0.78
.0010 "	22.02 " " "	0°37′51″	1.10
.0050 "	49.25 " " "	1°24′38″	2.46
.0100 "	69 66 " " "	1°59′42″	3.48
.0500 "	156.06 " " "	4°27′42″	7.80
.1000 "	221.20 " " "	6°18′41″	11.06

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The figures in the second column represent maximum values of F, attained at the time when the whole weight has become transferred to the obstruction, the "fictitious grade" then being as indicated in the last two columns. The mean value (F_m) of the tractive force per wheel, depends greatly upon the number and disposition of the obstructions. When they are relatively few in number, the mean value, F_m, may be very small as compared with the maximum value. When they are very numerous and so disposed as to make a practically continuous obstruction, the mean value will be approximately the same as that maximum instantaneous value which corresponds to the mean value of the fictitious grade. Between these two extremes the mean values of F may vary greatly. The mean value for the *train* (which is obtained in the manner already explained) is itself susceptible of considerable variation.

The increase in train resistance due to sand on the track has not been definitely determined. On steam roads it does not appear, however, to represent a very great increase in total tractive effort, probably because the "fictitious grade" has almost, if not entirely vanished by the time the locomotive and tender (which exert the greatest pressure densities) have passed over the sanded track. The additional tractive effort required. on account of the sand, may possibly be, therefore, *approximately constant, per train*; hence, when it is apportioned over the whole train weight (which is usually considerable) the resulting value, in pounds per ton, is likely to be small, probably seldom if ever exceeding 5 lbs. per ton. On street railroads, on the other hand, the effect of sand is generally considered to be much greater, the increase in train resistance on account of it being variously estimated at values ranging from 5 lbs. to 25 lbs. per ton.

The effects of dust, dirt and mud are practically negligible on all roads which have a private right of way, as is the general rule with steam roads, and as is also the case with many interurban electric roads. In the first place, the "*tee*" rail, used on all such roads, does not easily retain these substances. In the second place, it is only at grade crossings that there is oppor-

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tunity for their being deposited on the track by ordinary wheeled vehicles. On most street railroads, however, the case is entirely different. The top of the rail is usually below the level of the pavement, the result being, generally, as if the rail head formed the bottom of a depression (usually shallow, but sometimes quite deep), which forms a receptacle, and which generally accumulates a good share of about everything that is "loose" on the street, including sand, dust, dirt, grit, mud, refuse, etc. The depositing of these substances over the rail head is done in various ways, but mostly by horses and wheeled vehicles, especially the wheels of the latter, which, most of the time, roll in or near the grooves wherein the rails are placed, and act effectively as conveyors and distributors. The "obstruction" due to this deposit differs but little in nature and probably only little in degree also, in most cases, from that due to sand. It is generally regarded by engineers as the principal cause of the relatively great discrepancy in the train resistance values (lbs. per ton) found on steam railroads and on electric street railroads. The equivalent fictitious grade is supposed to vary, under different conditions, from 0.1 % to 1. % or or even more, representing (for a ton of 2000 lbs.) train resistance values ranging from 2 lbs. to 20 lbs. (or more) per ton.

The rolling friction caused by snow is not usually serious on steam roads, though it is not negligible in some cases.

The elevation of the rail above the ties and ballast usually allows sufficient room for the snow to be readily dislodged or pushed away sidewise, from under the wheel treads. In the case of deep and drifting snows, however, the rail is often covered again by the snow immediately after each wheel has passed. In such cases, although the snow yields readily under the pressure of each wheel, and therefore the fictitious grade is very low, yet, being present at each wheel of the train, and its "percentage" being practically the same for the whole train, it may sometimes cause an appreciable increase in the train resistance per ton. On street railroads the fictitious grade caused by snow is always appreciable, and in some cases, it may be relatively high, this result being due primarily to the peculiarity of

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construction of the track which we have justed noted. The depression in which the rail is placed facilitates the accumulation of the snow and the formation of a deeper and more compact layer over the rail head than would be possible in the case of ordinary tee-rail track construction. The process of dislodging the snow from under the wheel is more complicated and requires more pressure because the sides of the depression obstruct the snow which is squeezed off the rail head. Finally the admixture of dirt and mud, containing grit, with the snow that has to be thus squeezed off, further increases the resistance of the "obstruction." There is reason to believe that the train resistance due to snow on city street railroad tracks may amount to as much as 10 lbs. per ton, corresponding to a fictitious grade of 0.5 %. In the absence of more definite data, it may be assumed, provisionally, that the fictitious grade due to snow on the rails may range from 0.05 % to 0.5 %. The rolling friction due to ice and sleet may be considered as particular cases of that due to snow. There are no definite data available regarding the influence of this kind of rolling friction on train resistance. In all cases where the presence of ice or sleet renders the track too "slippery," *i. e.*, when the rail-friction is too much reduced, the necessity of using sand to increase the "adhesion" necessarily occasions a material increase in the train resistance. On city street railroads the ice formed from the muddy water covering the rail will contain grit, which, while preventing slip will also materially increase the train resistance.

The rolling friction due to non-yielding inequalities of surface is exemplified in the case of open or imperfect rail joints, also the "gap" at switch frogs, and the high or low spots on the rails. These are all "obstructions" of the "intermittent" kind, constituting, indeed, the best illustrations of that particular kind. In the case of an open rail-joint, the wheel first *falls* into the gap between the rail ends, and it is then lifted up bodily out of it, the lifting process being substantially identical with that involved in passing over an obstructing particle such as typified in Fig. 12. In the case of a high spot on the rail or a high end at a joint, the process may be reversed,

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the lifting action occurring *before* instead of *after* the falling down of the wheel. In every case, however, the lifting process involves the application of additional tractive force causing energy to be stored in the mass lifted, while the falling process causes a corresponding amount of the potential energy in the mass to be converted into kinetic energy. Only a portion, however, of this energy, — that equal to the horizontal component of the pulling motion, — is usefully recovered in *producing* tractive effort, the rest being lost in consequence of the impact (shock) which occurs when the wheel "strikes bottom." As in the case of all intermittent obstructions, the tractive effort required during the lifting action passes from zero through a maximum and returns to zero. It may be considered to have a small *negative* value during the falling action. The total tractive force involved at any point of distance or of time, is equal to the algebraical sum of the instantaneous values of the individual forces concerned. The mean value, F_m, and the train resistance value (lbs. per ton) are related to and obtainable from these values in the manner already explained. Since the obstructions of the kinds under consideration all have fixed locations on the track, their total number, per unit distance, will be constant, for a given portion of track. It is therefore obvious that the total number passed over, in unit-time, by each pair of wheels, will be in proportion to the velocity of the train. In the case of a short train running at very low speed and passing over only one of these obstructions at a time, their individual effects would be more noticeable, as a sudden but brief increase, amounting to a pulsation, in the total tractive effort applied to the train. As the train is made longer (*i. e.*, as the number of wheels is increased) and also as the speed is increased, these pulsations occur more and more often, until they "coalesce," so to speak, the resultant effect of all the obstructions being then virtually the same as if they were replaced by a "continuous" obstruction. The "fictitious grade," in this case, as we can see from the preceding considerations, is one whose "percentage" will increase with the speed. It will not, however, be influenced by the length of

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train, as in the case of rolling friction due to sand, but it will be practically independent of the number of wheels in the train. There are no reliable data regarding the train resistance values due to this form of rolling friction under different conditions. It is evident that these values must be greatly influenced by the condition of the track. When the track is well built, of heavy rails, and well supported (ballasted), and when it is maintained in first class condition, as is the case on the more important steam roads, the train resistance per ton, due to this kind of rolling friction must be small, and it may be even negligible. On tracks which are poorly built, with light rails, and which are in poor condition, on the other hand, it may assume considerable importance as a factor affecting the power required for traction. It was pointed out, many years ago, by Dr. P. H. Dudley, that inequalities of rail surface, causing considerable rolling friction, may be due to imperfections in the rails themselves. It was found that in some cases, owing to defects in rolling, and especially in straightening, the rails, they were "gagged" and their surface showed large numbers of minute undulations. So characteristic were these inequalities, that, in many instances, Dr. Dudley was able, from the graphical records obtained by running his "dynagraph" car over the track, to say at what mill the rails had been made. These defects have been minimized considerably in the last ten years by improvements in methods of rail manufacture, and undoubtedly, the decrease in train resistance in pounds per ton, which has taken place during this time, may be partly, though it cannot be wholly ascribed to these improvements.

The use of the term "hysteresis," in connection with train resistance was first suggested by an English engineer, Mr. A. Mallock, in the discussion of Mr. J. A. F. Aspinall's paper on "Train Resistance" before the Institution of Civil Engineers (Nov., 1901), to designate that portion of the train resistance which is due to the yielding of the rails and the ground, under the wheels. The term "track hysteresis" is a convenient one which may be used, with a slightly extended meaning, to cover, generally, all the yielding effects due to "continuous obstruc-

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tions" which are elastic to any degree and which do not involve *permanent* deformation. This extension of the term includes the yielding effect in the wheel tread and the rail head, which we have already noted, as well as all yielding effects produced by the bending of the rail, or the compression of the ties, the ballasts, the ground, etc., when the deformation is only temporary and is not permanent. These effects, which have hitherto been included in the class designated by the general term "miscellaneous resistances" are, as we shall see, clearly evidences or manifestations of rolling friction.

The phenomenon of track hysteresis presents the best illustration and the most important case of rolling friction involving a "continuous obstruction" and a *uniform* fictitious grade. Its primary cause is, simply, the circumstance that the restoration

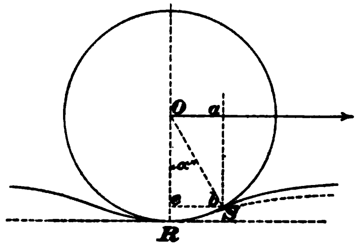

FIG. 11.

of the track to its original condition, or the "recovery" of the compressed parts of wheels, ties, rails, etc., *as a whole*, is not instantaneous, but consumes a perceptible amount of time. The result of this time-lag is (as indicated in Fig. 11) that the curve made by the portion of track *rising behind* the wheel is not the same as the curve made by the portion *falling before* the wheel, as should be the case if the parts compressed constituted a whole having elasticity and no "set." This means that the (theoretically) "recoverable" energy stored by compression, in the wheels and track, and capable of producing a tractive force which assists the motion of the car, in the manner already analyzed, is practically not all recovered. The discrepancy is easily explainable on the assumption (which appears well warranted) that during the process of compression, some of the parts, like

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the ties, ballast, ground, etc., are compressed somewhat beyond the elastic limit, at the expense of additional applied tractive force, above what would be otherwise required.

The energy corresponding to this additional force is "non-recoverable," being expended in some form of friction (mostly molecular) and ultimately converted into heat. A certain amount of "set" is at the same time produced in the parts compressed beyond the elastic limit. The restoration of these parts to their original condition, after the wheel has passed, involves a second expenditure of energy, substantially equal to the first; and this energy can only come from the "recoverable" energy stored in the parts which were *not* compressed beyond the elastic limit. Thus, each time that the track is depressed momentarily, there occurs a cycle of reactions which causes the abstraction of energy from the source of the moving force and its dissipation, by friction, etc., in very much the same way as in the case of "magnetic hysteresis."

The analogy of the "effect" of this kind of hysteresis to a "fictitious grade" is referred to by Mr. Mallock, in his discussion. He speaks of the car wheel as "always virtually climbing up a hill." He further states that "in his experiments that effect had come to something like between 1 in 250 (= 0.4 %) and 1 in 400 (= 0.25 %)." He considers it a very intricate function of the velocity. The preceding figures are doubtless average results for the whole train. They have little or no significance, however, in the absence of data concerning the conditions under which the experiments referred to were made. The average effective fictitious grade, due to track hysteresis, in the case of a car or train, is affected by and depends upon so many things that the study of the yielding effects produced at a single wheel is far from sufficient to give an adequate idea of the phenomenon as a whole, or to furnish a clue to the amount of total resultant effect on the train resistance in each case. The study of the phenomenon, in the case of a single wheel, shows that it is dependent upon the pressure-density produced at each wheel, the mechanical resistance (moment of inertia) of the rail, and the resistance of the ties, ballast, earth work, etc., opposed to

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compression or to deformation. When two or more wheels follow each other, as in the case of a car or train, the phenomenon is complicated by the introduction of additional variables, more especially the distance between the wheels. If, for example, the second wheel is placed as closely as possible to the first wheel, the two wheels will roll, so to speak, in a single hollow, common to them both. This means that the process of restoration of the track to its normal condition will practically begin only after the passage of the second wheel. As the distance between the two wheels is increased, there will become manifest a tendency of the rail to rise after the passage of the first wheel; this rise being, obviously, the more evident and more complete the greater the distance between the two succeeding wheels. There is, obviously, in each case, a certain minimum distance between succeeding wheels, inside of which the "recovery" of the track will not be complete and beyond which it will be complete; the hysteresis effect at any succeeding wheel in the latter case being exactly the same as at the first wheel.

We have just seen that the only energy loss involved in track hysteresis is that which is expended in producing "deformation" or "set" and in removing it. Now, in the case of two wheels placed closed together, this process of producing and removing deformation, practically occurs only once for the two wheels, instead of twice as would be the case if the second wheel were placed at a sufficiently great distance behind the first wheel. It follows, therefore, that track hysteresis will not only depend upon the total number of wheels (*i. e.*, upon the length of the train), but also upon the arrangement of these wheels, or, to be more exact, the distance between them. In the case of a long passenger car, the distance between the rear wheel of the forward truck, and the front wheel of the rear truck, is sufficiently great to allow an almost, if not entirely complete "restoration" of the track between the two trucks. This means that the hysteresis cycle will involve quite nearly, if not exactly, the same energy loss as the cycle occurring at the first truck. In practice, when passenger cars are coupled up together in trains, there is less track space between the end

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wheels of two different cars than there is between the two trucks of the same car; consequently, the rise of the track between two cars is less than between the two trucks of the same car, and the hysteresis cycle for the rear truck is greater than that for the front truck, for each car, since the latter is all the time literally "following in the wake" of, or rolling in the "hollow" made by, the rear truck of the preceding car. In the case of freight cars, which are usually much shorter, the distance between the nearest wheels of front and rear trucks is smaller (the spacing between trucks being about 20 ft. for cars of 60,000 lbs. capacity), and the "restoration" or rise of the track which occurs between the two trucks is less than in the case of passenger cars (where the spacing varies from 30 to 44 ft.). Consequently, the loss by track hysteresis ought to be less in the case of freight cars than in the case of passenger cars, for the same pressure-density, or the same weight per axle. All tests show this to be true.

From the preceding study of the manner in which loss of useful energy is caused by track hysteresis, we can readily see that in order to reduce this loss it is necessary to reduce either the *number* or the *amplitude* of the hysteresis cycles produced per car or per train, at each portion of the track. The case of several wheels rolling in the same "hollow" suggests the ideal condition for this purpose to be one where the whole train weight is so distributed on or received by the track that there is only one "hollow" in the entire portion of the track covered by the train, and, consequently, only a single hysteresis cycle is produced by the passage of that train. The decrease in train resistance effected in the last few years may be ascribed principally to the efforts made to realize this ideal condition in actual practice. The highest credit is due, in this connection, to Dr. P. H. Dudley, whose name should be at the very head of the list of investigators of railroad track phenomena and problems who have done the most, directly or indirectly, to bring about this valuable result.

(Omission will be made, for lack of space, of an extended reference, illustrated with numerous lantern slides, made, at

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this point, in the lecture, to Dr. Dudley and his valuable work, including a description of his "dynagraph" car, for automatically "inspecting" railroad tracks and graphically recording all details of their condition at all points, also his "stremmatograph" for measuring the deflections and the fibre strains produced in the rail, at any point, by the passage of a given train, also a summary of the improvements in "comparative condition of tracks," per year, from 1881 to 1902, resulting from scientific methods of rail design and track construction.)

Dr. Dudley had noticed, nearly twenty-five years ago, in making a series of experiments on train resistance on several roads, that the train resistance decreased sensibly when running over new rails, after passing over old worn rails, although the topographical conditions of the line remained substantially the same. These experiments (made on rails 4 to 4.5 inches high and weighing from 56 to 63 lbs. per yard when new), indicated the presence of yielding effects in the track which increased as the rails became worn. It was soon afterward noted by Dr. Dudley that even when these rails (which were the "standard" rails in 1880 and for some years afterward) were new, and even when the greatest care was taken in "surfacing" the track, the yielding effect was still too great and too much "localized," that is to say, the mechanical stiffness (moment of inertia) of the track was insufficient to cause the wheel loads to be distributed over a great enough length of rail to make a smooth track. This led Dr. Dudley to make a systematic comprehensive study of the physical and mechanical principles involved in these yielding effects. He appears to have been the first to recognize the important analogy between a loaded track and a girder beam which is not uniformly loaded. He noticed and studied carefully the fact that each truck of a car makes a "general" depression in the track, by its total weight, "specific" or "individual" deflections being at the same time produced under each wheel; the conditions being analogous to a girder whose load is applied at a few points. It being impracticable to make material changes in the loads or their manner of application to the track by changing the number or the spacing of the car wheels, Dr.

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Dudley sought to reduce the deflections by increasing the stiffness of the rails. This led, about 1883, to the design and the introduction into use on some roads, of a rail 5 inches high weighing 80 lbs. per yard, and having a mechanical stiffness 60 to 70 percent greater than that of the 4.5 inch rail; the consequence being that the yielding effects (termed "deflections" by Dr. Dudley) were diminished to less than half the previous amount, as shown by the dynagraph car diagrams. The possibility of increasing the weight and the power of locomotives, and of handling heavier trains, on heavier rails, stimulated their adoption by many roads, and, by 1890, their use had become quite general on the Eastern lines of this country. The maximum axle load, which, in 1880 and for several years after, had been limited to 27,500 lbs., began to be increased about 1886, and, by 1890, it had reached 40,000 lbs. Considerable study and many experiments were devoted, in the meantime, by Dr. Dudley, to the important object of further increasing the "stiffness" of a rail without increasing its weight (on which its *cost* depends) by a different distribution of the metal, or by changing the "cross-section" of the rail, so as to increase its moment of inertia. The result was the 5.125 in. "80-lb." rail, the principal feature of which was a wider and flatter head. The importance of designing rails so as to secure the maximum stiffness for a given weight was emphasized by Dr. Dudley in some very instructive remarks made by him before the American Institute of Electrical Engineers, Feb. 24, 1891 (Vol. VIII, pp. 82, 83 and 86–88). The fact that Dr. Dudley had in contemplation the use of still stiffer rails than the 5.125 in. "80-lb." rail, at this time, is shown by his reference to some 95-lb. rails, "which he had just made for a road, which will be very much stiffer than the 80-lb. rails," and also his reference to his design of a 105-lb. rail "which are nearly 100 % stiffer than the 80-lb. rails." He states, incidentally, that "All trials show a very material reduction in train resistance with the heavy rails, as we increase the stiffness." The heaviest and stiffest rail in regular use at the present time is the 6-inch 100-lb. rail, which first came into use as far back as 1892. The increase in

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the stiffness of the rails has permitted a still further increase in the maximum locomotive axle load, which is now 50,000 lbs. and even more.

In the case of the larger freight cars, of capacity ranging from 80,000 lbs. to 100,000 lbs., the wheel-base of the trucks has been increased and the spacing between the trucks has been decreased. Dr. Dudley's investigations show that with freight trains made up of such cars, running on very heavy and stiff rails, there is practically only one general, continuous, depression of the rails, sleepers, ballast, and road-bed, which extends from the front pilot-wheel of the locomotive to the last wheel of the "caboose" at the rear end of the train. There is still evidence of the "specific" or "individual" deflections under the wheels, but these are very small. The track forms a practically continuous girder which is "restrained," or, as Dr. Dudley prefers, "*constrained*," by the stiffness itself of the rail, to such an extent that the rise or "restoration" of the rail surface, in the unloaded portions, between the wheels, is greatly restricted. The practical consequence of this constrained condition is that the passage of the entire freight train causes only one hysteresis cycle of the full amplitude. The small "specific" deflections just noted produce only minute, relatively insignificant cycles, which might be termed "sub-cycles." These occasion a very small energy loss, as compared with the principal cycle. The ideal condition previously referred to is thus found to be realized, to a great extent, in practice, in such cases. The train resistance, for these cases, as due to track hysteresis, may, therefore, be regarded as approximately constant *per train* somewhat like that due to "sand"; the result being that it will be relatively small in the case of long and heavy freight trains. According to Dr. Dudley, the train resistance for long and heavy freight trains, which, in the days of 4.5 inch rails, ranged from 7 to 8 lbs. per ton, is now only about half this amount. This reduction of train resistance is not all due to the diminution of track hysteresis, however. The increased pressure on the journal bearings, as the result of greater weights per axle, causes the coefficient of journal friction to be diminished, as we

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have already seen. The increase in the *length* of freight trains may also be a factor here, though of less importance, in the reduction of the train resistance.

In the case of passenger cars, according to Dr. Dudley, the portion of the rail which happens to be in the center of the wheel spacing (*i. e.* under the middle of the car), is generally "relieved" of strain, partly or wholly, according to the length of the car and of this spacing. Consequently, the depression under the whole train is not a general or a continuous one, as in the case of freight cars; and the loss of power by track hysteresis is much greater, being, in this case, practically proportional with the number of *cars*. This accounts, in part, for the higher train resistance found in the case of passenger trains, on steam roads.

It is evident that the same "formula" for rolling friction (considered alone), would not fit the two cases just noted, without being modified. Indeed, the extent to which the three principal forms of rolling friction vary, and, especially, the relatively great number of circumstances affecting or influencing the variations, indicate the great difficulty of devising a single, simple, yet sufficiently comprehensive formula which will be applicable to all cases.

(*To be continued.*)

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THE INDUCTION MOTOR.

By C. A. Adams, Assistant Professor of Electrical Engineering, Harvard University.

(Continued from November, 1904.)

III.

In the second part of this article the vector diagram of the Induction Motor was developed and explained in some detail. The writer wishes again to emphasize the importance of a thorough understanding of this diagram, and a thorough appreciation of its limitations. These arise from the assumptions made at the outset, which were chiefly to the effect that all currents, e. m. f.'s, and peripheral current and flux distributions were sinusoidal.

The sinusoidal current distribution assumes a large number of phases, which is impracticable, three being the practical limit. With this number the active conductors of a single-phase belt * are usually distributed in several slots, the peripheral width of the belt varying from about 2 inches in a 60-cycle motor, to 4 inches in a 25-cycle motor. Thus, since the peripheral current density is constant at any instant over a given belt, the current distribution does not vary gradually from point to point, but by steps of considerable size.

If the secondary has a two- or a three-phase winding, as is usually the case in large motors and frequently in small ones, the partial overlapping of a secondary phase belt on two primary phase belts results in local unbalanced m. m. f.'s, due to the currents I_2 and I'_1, even assuming that the r. m. s. and average values of these currents are equal. This disturbance may be classed in general under *differential action*, due to the width of a single phase-belt and the consequent fact that the action in different parts of that belt is at times in opposite

* The conductors per phase and per pole.

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directions and thus wasteful. This differential action may relate to the m. m. f. (as above) or torque of the current in, or to the e. m. f. generated by the different parts of a single belt. The latter is usually taken account of in the calculation of induction motors, by the introduction of a constant less than unity, which will be hereinafter called the *differential factor*; but heretofore no account has been taken of the differential action between the currents I_2 and I'_1, as above noted. If the secondary is of the squirrel cage type, this last is negligible as is that of e. m. f. generation in the secondary, owing to the fact that each secondary conductor is to all intents and purposes an independent phase, and the width of the phase-belt is thus reduced to a minimum. The presence of teeth and the distortion of impressed wave shape may also introduce considerable complications.

These points should be borne in mind in connection with the following mathematical analysis, which is based upon the diagram and its underlying assumptions, since a course of reasoning carried out by mathematics does not differ from one carried out by any other mode of expression; the result contains no information not contained in the premises, but merely puts that information into a more useful form. Thus no matter how completely and exactly the mathematical transformations may be made, the accuracy of the result is limited by the legitimacy of the assumptions upon which is based the method of analysis.

This point is emphasized because of the frequency of its neglect and the consequent disappointment when comparison is made between calculated and observed results.

Algebraic Analysis of the Relations Existing between the Several Variables and Constants of the Induction Motor.

This analysis reveals nothing not implied in the vector diagram, as it is merely an algebraic statement and transformation of the relations there shown graphically. Some of the results are however in a much more convenient form.

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Equivalent Circuit Scheme.

A little consideration will show that the equivalent circuit scheme represented by the induction motor diagram is that of Fig. 24. Thus the mutual flux Φ is proportional to E'_1, and I_0 is approximately proportional to Φ; I_0 may then be considered as being produced by the e. m. f. E'_1 in a separate circuit of resistance r_0 and reactance x_0 or of conductance g_0 and susceptance b_0; r_0 and g_0 relate to the energy component of I_0 and are determined by the core losses, while x_0 and b_0 relate to the wattless or magnetizing component and are determined by the reluctance of the main magnetic circuit. As the reluctance of this main path is approximately constant, so are x_0 and b_0. If r_0 and g_0 were constant, the energy component of I_0 would be proportional to E'_1 and the core losses proportional to the square of E'_1 or of Φ; but since the core losses are more nearly proportional to the 1.6th power of Φ, it is evident that the energy component of I_0 increases a little less rapidly than E'_1 and that r_0 and g_0 decrease slightly with increasing flux.

However, since E' and Φ are nearly constant during the normal operation of any given motor, and since this energy component is a small part of the whole current, the assumption that

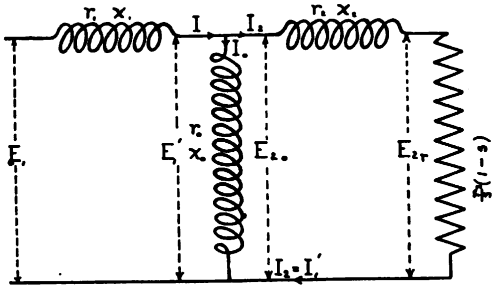

FIG. 24.

r^0 and g_0 are constant will introduce an exceedingly small error.

It has already been shown that the secondary current I_2, or its equivalent I'_1, is the same as would be produced by the e. m. f.

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E_{20} $(=E'_1)$ in a circuit of resistance, $\frac{1}{s}r_2$, and reactance x_2;* also that this circuit may be subdivided into two portions, one of resistance r_2 and reactance x_2, and the other of non-inductive resistance $\left(\frac{1}{s}-1\right)r_2$, which represents the load and varies with the slip. From this standpoint the induction motor is exactly analogous to an ordinary transformer with a variable non-inductive resistance in the external secondary circuit.

The two currents I_0 and I_2 $(=I'_1)$ which are produced by the same e. m. f. E'_1, and which combine to make the total primary current I_1, may thus be considered as flowing in two parallel circuits branched off from the main primary circuit as in Fig. 24.

With this introduction, the algebraic statement follows naturally.

Consider first the secondary and exciting circuits in parallel; their equivalent resistance and reactance are found in the ordinary manner, Fig. 25.

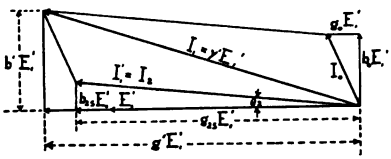

FIG. 25.

$g_0 = \frac{r_0}{z_0^2}$ is the exciting conductance;

$b_0 = \frac{x_0}{z_0^2}$ is the exciting susceptance;

$y_0 = \sqrt{g_0^2 + b_0^2} = \frac{1}{z_0}$ is the exciting admittance;

$g_{2s} = \frac{r_{2s}}{z_{2s}^2}$ is the total secondary conductance, where

* As in Part II it is here assumed throughout that the secondary quantities are reduced to primary turns.

$r_{2s} = \frac{r_2}{s}$ is the total equivalent secondary resistance, and

$z_{2s} = \sqrt{r_{2s}^2 + x_2^2}$.

$b_{2s} = \frac{x_2}{z_{2s}^2}$ is the secondary susceptance, and

$y_{2s} = \sqrt{g_{2s}^2 + b_{2s}^2} = \frac{1}{z_{2s}}$ is the secondary admittance.

Designate the equivalent constants for these two circuits in parallel by r', x', g', b', etc. Then

$$\left.\begin{aligned} g' &= g_0 + g_{2s} \\ b' &= b_0 + b_{2s} \\ y' &= \sqrt{g'^2 + b'^2} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (28)$$

$$\left.\begin{aligned} r' &= \frac{g'}{y'^2} = \frac{r_0 z_{2s}^2 + r_{2s} z_0^2}{(r_0 + r_{2s})^2 + (x_0 + x_2)^2} \\ x' &= \frac{b'}{y'^2} = \frac{x_0 z_{2s}^2 + x_2 z_0^2}{(r_0 + r_{2s})^2 + (x_0 + x_2)^2} \\ z' &= \sqrt{r'^2 + x'^2} \end{aligned}\right\} \quad . \quad . \qquad (29)$$

Then the total equivalent constants for the whole motor are (see Fig. 26) —

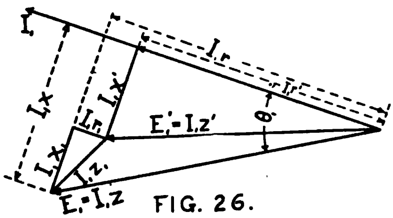

FIG. 26.

$$\left.\begin{aligned} r &= r_1 + r' \\ x &= x_1 + x' \\ z &= \sqrt{r^2 + x^2} \end{aligned}\right\} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (30)$$

It will aid much in obtaining a grasp of the equations that follow, to connect clearly each of the above constants and each of the equations with the circuit scheme of Fig. 24.

The more important constants are plotted against s for a typical motor, in Fig. 27.

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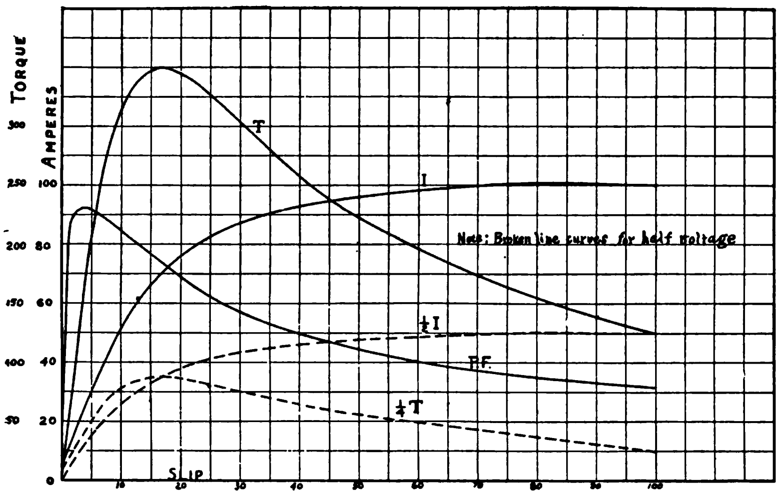

FIG. 27

The *primary current* is then —

$$I_1 = \frac{E'_1}{z'} = \frac{E_1}{z} \qquad (31)$$

The power factor is —

$$\cos\theta_1 = \frac{r}{z} \qquad (32)$$

From Fig. 26 —

$$E'_1 = E_{2\,o} = E_1 \frac{z'}{z} \qquad (33)$$

Then —

$$I_2 = I'_1 = \frac{E_{2\,o}}{z_{2\,s}} = E_1 \frac{z'}{zz_{2\,s}} \qquad (34)$$

and

$$I_o = \frac{E'_1}{z_o} = E_1 \frac{z'}{zz_o} \qquad (35)$$

The *input* is —

$$P_1 = p\,E_1\,I_1 \cos\theta_1 = p\,\frac{E^2_1}{z^2}\,\mathrm{r} \qquad (36)$$

where p is the number of phases.

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From eq. (26) page 223, the *output* (including friction) is —

$$P_2 = p\, E_2{}^2{}_0\, \frac{(1-s)\, r_{2s}}{r_{2s}^2 + x_2^2} = p\, E^2{}_1\, \frac{z'^2}{z^2}\, \frac{(1-s)\, r_{2s}}{z_{2s}^2} \quad . \quad (37)$$

The *torque* * is —

$$T = \frac{P_2}{\text{angular velocity}} = \frac{pp'}{2\pi n}\, E^2{}_1\, \frac{z'^2}{z^2}\, \frac{r_{2s}}{z_{2s}^2} \quad . \quad . \quad (38)$$

and the *efficiency* (friction neglected) is —

$$\frac{P_2}{P^1} = (1-s)\, \frac{z'^2}{z_{2s}^2}\, \frac{r_{2s}}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad (39)$$

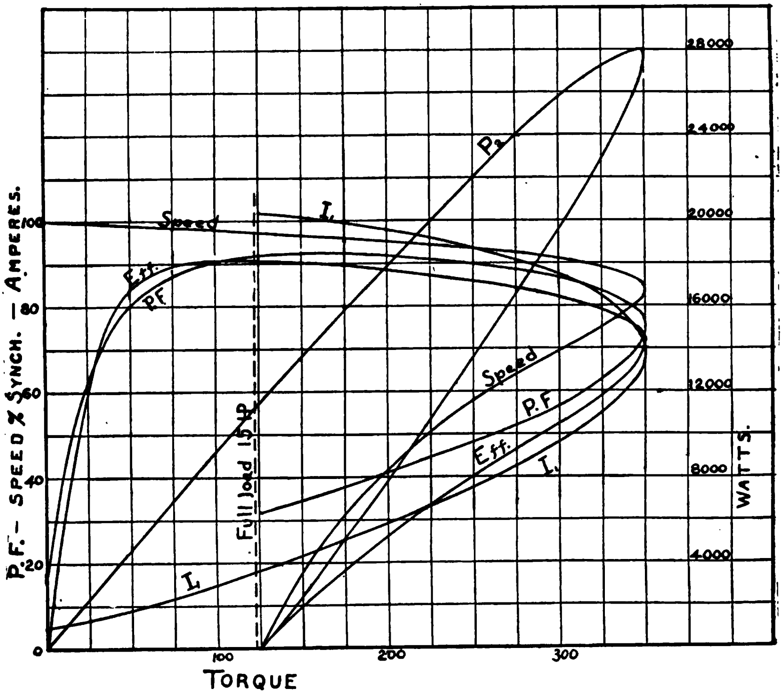

FIG. 28.

* The unit of torque here used is that of the practical electromagnetic system, corresponding to the volt, ampere, watt, etc. Unfortunately, there is no accepted name for this unit. It is equal to 10^7 dyne centimeters, .102 Kg. meters, or .737 lb. ft. The torque of eq. 27 is expressed in these same units, *not* in synchronous watts.

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Thus, for any given value of s, the *input*, *output*, and *torque* are proportional to the square of the impressed e. m. f.; the *power factor* and *efficiency* are independent of it; and the currents are proportional to it. This is illustrated by the curves of Fig. 27 for a 15–H. P. motor, with the following constants: $r_0 = 8$, $x_0 = 50$, $r_1 = r_2 = .4$, $x_1 = x_2 = 1.2$. The solid curves correspond to the normal voltage 440, and the broken curves to 220 volts.

In Fig. 28 the same curves (for normal E_1) are plotted against the torque. This is a more common form of plotting.

The motor is star connected, so that the volts per phase in the two cases are $E_1 = 254$ and $E_1 = 127$ respectively.

The torque curves for full and half voltage show clearly the importance of holding up the impressed e. m. t., (unless the margin between full load and breakdown is normally a large one).

Above are all the important characters of the Induction Motor expressed in terms of its constants,* of the slip and of the impressed e. m. f.; or since the latter is usually constant, the characteristics are expressed as functions of the slip, s, or of 1-s which is the speed in percent of synchronous speed.

When the equations are expanded, it will be found that the induction motor variables are for the most part fairly complicated functions of the slip, and that the calculation of the characteristic curves for a given set of constants is a considerable task.

Calculation.

Nevertheless it is recommended that for purposes of calculation the formulae be used in their complete form; for although

* It has already been noted that g_0, the exciting conductance, is not strictly constant, and it will be shown later that the leakage reactances vary somewhat from no load to full load, owing to the saturation of the iron portions of the leakage paths. The reluctance of the main flux path also increases slightly with the load, due to the saturation of the tooth corners and sometimes of the teeth; so that b_0 and x_0 are not strictly constant. Moreover, the change in temperature of the windings cause considerable changes in the resistances of those windings, r_1 and r_2.

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certain approximations can be made without seriously impairing the accuracy of the results for special cases, in others the errors may be considerable. The inherent errors already mentioned are sufficient, without adding unnecessary ones.

For *approximate calculations* a graphical method will be given later.

Analysis.

For purpose of analysis the complete diagram, Fig. 22, will serve very well in some cases, *e. g.*, in the investigation of the manner in which the several constants affect the power-factor or the current; but there are other important points best considered with the aid of approximate equations.

Approximate Equations.

The most effective approximation for this purpose is to neglect the effect of I_0 upon the drop of voltage between E_1 and E'_1. Then equation 33 becomes—

$$E'_1 = E_{2\,0} = E_1 \frac{z_{2\,s}}{z_s} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (40)$$

where $z_s = \sqrt{r^2_s + x^2_s}$, $r_s = r_1 + r_{2\,s}$, and $x_s = x_1 + x_2$.

It is obvious that z_s is the series impedance of the primary and secondary circuits, the exciting circuit being neglected. A glance at the diagram, Fig. 22, will show that with ordinary constants, that part of the primary impedance drop due to I_0 is approximately in phase with E'_1 and contributes largely to the numerical difference $E_1 - E'_1$. The value of E'_1 as given by equation 38 is from 2% to 5% too large throughout the normal range of operation. Moreover, since E'_1 enters as the square in P_2 and T, this error will be doubled; it is therefore not at all negligible from the standpoint of *calculation*, although it serves well for a rough analysis.

Substituting in equation 37 gives —

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$$P_2 = p\frac{E^2{}_1}{z^2{}_s} r_{2s}(1-s) = pE^2{}_1 \frac{\frac{r^2}{s}(1-s)}{\left(r_1+\frac{r_2}{s}\right)^2 + (x_1+x_2)^2} \qquad (41)$$

where $\frac{E^2{}_1}{z^2{}_s}$ is the square of the current that would flow when the exciting circuit is omitted, and $\frac{r_2}{s}(1-s)$ is the equivalent load resistance (see Fig. 24).

Maximum Output.

Placing $\frac{dP_2}{ds} = 0$ gives—

$$s = \frac{r_2}{r_2+\sqrt{(r_1+r_2)^2+(x_1+x_2)^2}} \quad . \quad . \qquad (42)$$

where $\sqrt{(r_1+r_2)^2+(x_1+x_2)^2}$ is the series impedance of primary and secondary when $s = 1$, *i. e.* at standstill.

Then the maximum output is—

$$P_{2\,max} = \frac{pE^2{}_1}{2[(r_1+r_2)+\sqrt{(r_1+r_2)^2+(x_1+x_2)^2}]} \qquad (43)$$

Referring to equations 42 and 43, and remembering that ordinarily r_2 and (r_1+r_2) are small when compared with $\sqrt{(r_1+r_2)^2+(x_1+x_2)^2}$, it appears that—

The slip at which the maximum output occurs is roughly proportional to r_2, and inversely to $\sqrt{(r_1+r_2)^2+(x_1+x_2)^2}$; also that the maximum output is roughly inversely proportional to $\sqrt{(r_1+r_2)^2+(x_1+x_2)^2}$.

Substituting (40) in (38), gives—

$$T = \frac{pp'}{2\pi n}E'^2_1\frac{r_{2s}}{z_{2s}^2} = \frac{pp'}{2\pi n}E^2{}_1\frac{\frac{r^2}{s}}{\left(r_1+\frac{r_2}{s}\right)^2+(x_1+x_2)^2} \qquad (44)$$

This is the same as equation (11), page 79, except that here the primary drop of pressure is partly taken account of, as indi-

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cated by the presence of r_1 and x_1. Its analysis will also yield essentially the same results as regards the shape of the speed-torque curve.

Maximum Torque.

Placing $\frac{dT}{ds} = o$, gives —

$$s = \frac{r_2}{\sqrt{r_1^2 + (x_1 + x_2)^2}} \qquad . \quad . \quad . \quad . \qquad (45)$$

and the maximum torque is —

$$T_{\text{max.}} = \frac{pp'}{2\pi n} \frac{E_1^2}{2(r_1 + \sqrt{r_1^2 + (x_1 + x_2)^2})} \qquad . \quad . \qquad (46)$$

Thus *the slip at which the maximum torque occurs is proportional to* r_2, (as in equation 14 where r_1 and x_1 were neglected) *and approximately inversely proportional to the total leakage reactance,* $x_1 + x_2$. Also *the maximum torque is independent of* r_2 (in equation 15 and Fig. 16) *and approximately inversely proportional to the total leakage reactance,* since r_1 is small compared to $x_1 + x_2$.

Starting Torque.

Placing $s = 1$ in equation 44,

$$T_0 = \frac{pp'}{2\pi n} E_1^2 \frac{r_2}{(r_1 + r_2)^2 + (x_1 + x_2)^2} \qquad . \quad . \quad . \qquad (47)$$

which, *for small values of* r_2, *is approximately proportional to* r_2 *and inversely to* $(x_1 + x_2)^2$. This last is a very important point and will be considered below in connection with methods of starting.

Maximum Starting Torque.

The value of r_2 which makes T_0 a maximum is obtained by placing $s_{\text{Tmax.}} = o$ in equation 45. It is —

$$r_2 \text{ (for max. starting torque)} = \sqrt{r_1^2 + (x_1 + x_2)^2} \qquad (48)$$

and the maximum starting torque is the same as that of equation 46.

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Starting Current.

Neglecting the exciting current,* the starting current is —

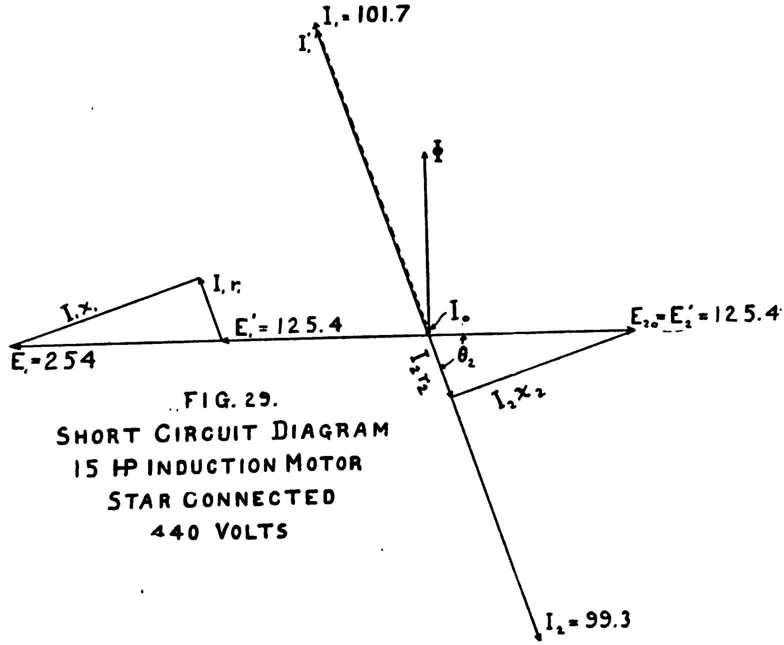

FIG. 29.
SHORT CIRCUIT DIAGRAM
15 HP INDUCTION MOTOR
STAR CONNECTED
440 VOLTS

$$I_{1\,0} = \frac{E_1}{\sqrt{(r_2 + r_2)^2 + (x_1 + x_2)^2}} \qquad . \quad . \quad . \quad (49)$$

Then —

$$T_0 = \frac{pp'}{2\pi n} r_2 I_1{}^2{}_0 = \frac{pp'}{2\pi n} E_1 I_{1\,0} \frac{r_2}{\sqrt{(r_1 + r_2)^2 + (x_1 + x_2)^2}} \quad (50)$$

Since I_0 was neglected, $I_{1\,0}$ is the secondary as well as the primary starting current, and the starting torque is thus propor-

* As the slip increases from no load, I'_1 increases and I_0 decreases (since the primary drop increases and E'_1 decreases accordingly). In a good motor, the exciting current at standstill is only about 3% of the load current. The decrease in I_0 also reduces the error introduced by the approximation of equation 40, this error being relatively small at standstill, when E'_1 and I_0 have usually less than half of their no load values. The standstill or short-circuit diagram for the motor of Figs. 27 and 28 is drawn to scale in Fig. 29.

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tional to the secondary copper loss at standstill. But this might have been predicted, since the starting torque is due only to the power transmitted across the gap to the secondary. In some motors the secondary core loss at standstill is considerable, which may add appreciably to the starting torque.

EFFICIENCY OF STARTING TORQUE.

One of the most serious charges against the induction motor is that its starting current is inherently large as compared with the starting torque. The reason for this is two-fold: first, the torque-producing effect * of the secondary current is reduced by its lag behind its e. m. f. $E_{2\,o}$, and in the ratio $\cos\ \theta_2 = \frac{r_2}{\sqrt{r_2 + x_2{}^2}}$; second, the flux upon which the current reacts to produce the torque, and which is proportional to and represented by $E_{2\,o}$ ($= E'_1$), is much reduced, owing to the drop in the primary winding, due to r_1 and x_1.

In the ideally perfect motor, without losses or leakage, both of these causes are absent since $r_1 = x_1 = x_2 = o$, $E_{2\,o} = E^1$ and $\cos\ \theta_2 = 1$.

Then the starting torque would be (see eq. 47) —

$$T_{oo} = \frac{pp'}{2\pi n}\frac{E_1{}^2}{r_2} = \frac{pp'}{2\pi n} E_1 I_{1\,oo},$$

or, the starting torque per ampere for the ideal motor is —

$$\frac{T_{oo}}{I_{1\,oo}} = \frac{pp'}{2\pi n} E_1,$$

and for the real motor (see eq. 50) —

$$\frac{T_o}{I_{1\,o}} = \frac{pp'}{2\pi n} E_1 \frac{r_2}{\sqrt{(r_1 + r_2)^2 + (x_1 + x_2)^2}}$$

The ratio of the real to the ideal may then be defined as the *efficiency of starting torque,* and is —

$$Eff_{To} = \frac{r_2}{\sqrt{(r_1 + r_2)^2 + (x_1 + x_2)^2}} \quad . \quad . \quad . \quad (51)$$

This may serve as a basis for comparing the starting qualities

* See Part I, pages 75–81, April, 1904.

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of the induction motor with those of the d. c. motor, in which, with the same assumption (exciting current neglected), the starting-torque efficiency is nearly 100 %. It cannot be high in the case of the induction motor without separate starting resistance; in that case it frequently exceeds 90 %. With squirrel cage motors it varies from 10 % to 40 %. The latter is unusual and can be obtained only at the sacrifice of efficiency and speed regulation, *i. e.* by making r_2 large.

It will be interesting to investigate the *starting-torque efficiency* for the case of *maximum starting-torque*, *i. e.* with $r_2 = \sqrt{r_1^2 + (x_1 + x_2)^2}$ *, (see eq. 48). Substituting this in eq. 51, gives —

$$Eff_{\text{To max.}} = .707 \sqrt{\frac{\sqrt{r_1^2 + (x_1 + x_2)^2}}{r_1 + \sqrt{r_1^2 + (x_1 + x_2)^2}}} \quad . \quad . \quad (52)$$

If $(x_1 + x_2)$ is relatively very large, this approaches the value .707, and if $(x_1 + x_2)$ is relatively very small, it approaches the value .5. For normal proportions it is not far from .64, and is independent of r_2. The reason why the larger values of $(x_1 + x_2)$ give larger values in eq. 52 is that with the earlier breakdown torque (see Fig. 17, April, '04), a larger value of r_2 is required to bring the maximum torque at standstill.

Undesirability of Leakage.

Referring now to equations 47 and 51, it will appear that one of the chief obstacles to high starting torque and high starting-torque efficiency is the leakage reactance, $x_1 + x_2$; and although it also has a very undesirable effect upon other characteristics of operation (*e. g.*, power factor), its undesirability cannot be better illustrated than in connection with the simpler methods of starting squirrel cage motors.

The Starting of Squirrel Cage Motors.

Owing to the rugged simplicity of this type of induction motor, it should be used wherever possible; but if it is thrown

* This condition is practically impossible without separate starting resistance.

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directly on the line at starting, it takes a current from 3 to 8 times the full load running current and at such a low power factor that, except with very small motors, the drop along the line (and even in the generator unless it be relatively very large) is excessive and very undesirable. To avoid this, a compensator (or auto-transformer) is employed to supply the motor at reduced voltage; but the starting torque is proportional to the square of the voltage, and if the latter be reduced one-half, T_0 will be reduced to one-fourth of its full-voltage value.

Suppose the motor in question is that whose speed torque curve is shown in Fig. 30, No. 1, its full voltage starting torque is less than one-third of the normal running torque, so that the starting torque for half voltage will be only 8% of the full load

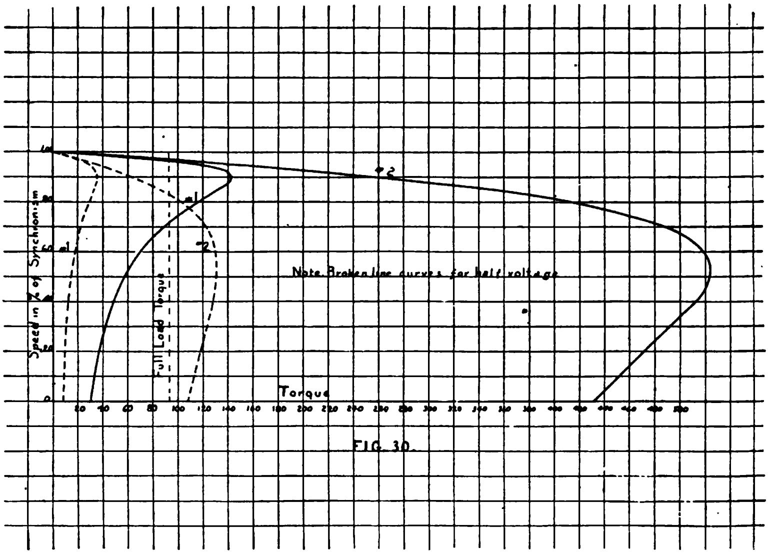

FIG. 30.

torque, which is only permissible in a motor which is never required to start under any load whatever. A tight belt would alone prevent its starting without assistance.

The starting current, even with this low torque, is more than that for full load.

Curve No. 2 shows a motor with the same constants except

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as regards leakage, the leakage reactance being one-fifth of that of No. 1.

A comparison of these two motors, for starting, is made in Table I, which speaks for itself.

Table I.

Motor	Full voltage.			¾ Full voltage.			½ Full voltage.			⅓ Full voltage.		
	T_0	I_{10}	I	T_0	I_{10}	I	T_0	I_{10}	I	T_0	I_{10}	I
No. 1	.32	2.5	2.5	.18	1.88	1.4	.08	1.25	.625	.035	.83	.28
No. 2	4.7	10.2	10.2	2.65	7.65	5.7	1.18	5.12	.55	.52	3.4	1.14

T_0 is the starting torque, I_{10} the starting current, and I is the current taken from the line, all in percent of full load running values.

The two motors are extremes, but not impossible. They illustrate the *necessity* of low reactance in squirrel cage motors,

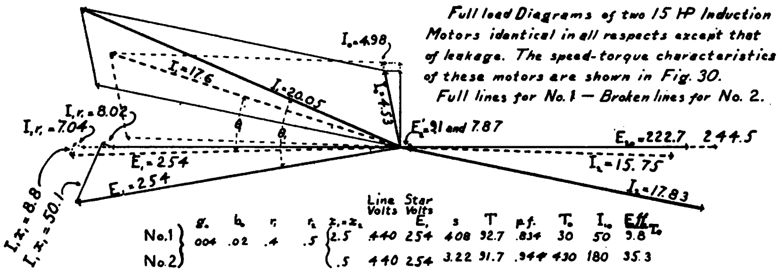

FIG. 31

and the fact that with a very low reactance this type of motor will start with more than full torque when taking only 2.5 times full current from the line, or with one-half full torque when taking only a little more than full current from the line. Such a motor is larger and more expensive to build, has a larger exciting current and a somewhat lower power factor on that account; but the sacrifice is well worth the gain in simplicity and robustness.

This subject will be further discussed under "Design," in a later installment of this article.

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Editorial.

FOR the purpose of promoting the general knowledge and discussion of Engineering subjects together with the social inter-

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Our Societies are comparable to the organizations which mean so much to Engineers in practical life. They are valuable to the members both from the good fellowship which they develop, and from the speakers with whom they are privileged. At their meetings a student meets men with common interests, men with whom he will come in contact during later life. The meetings give also the chance to hear and to know personally men who stand high in their professions.

In several of the clubs frequent discussions and papers by students themselves make them still more valuable.

Graduate Notes.

Mr. A. S. Hawks, M. E. '00, has recently come to the Scientific School as assistant in Engineering. Previously he had been engineer of the Conrey Placer Mining Co. of Virginia City, Montana, where a placer gold mine was worked by dredging machinery. After leaving Montana, Mr. Hawks was in the erecting shops of the Nordberg Mfg. Co. Milwaukee, and in the gas engine departments of the Allis-

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Chalmers Co. and of the Power Mining Machinery Co., Cudahay, Wis., as checking and designing draftsman.

Moses King, Jr., '04, is working in the testing room of the Western Electric Co., New York City. Home address, 2 West 88th St., New York, N. Y.

John Howe Hall, '03, is now in the Crucible Steel Department of the Bethlehem Steel Co. Home address, 505 Cherokee St., So. Bethlehem, Pa.

Mr. J. A. Moyer, '99, is in charge of calculations for experimental work for the General Electric Co. at Lynn, Mass. Mr. Moyer was formerly an instructor at the Lawrence Scientific School and an associate editor of the JOURNAL.

Harvard Engineering Camp.

Through the generosity of a friend of the University, the Engineering Camp at Squam Lake, N. H., has been able to purchase about two hundred acres of very desirable land, adjacent to the old property. This, with the small ponds at the foot of Red Hill and elsewhere, together with hydrographic work in Squam Lake will be the basis of next year's work in surveying.

Since last summer, the camp has been improved by better sanitary arrangements, by broader piazzas, for out-of-door dining, with railings and comfortable benches, and by more ample accommodations in the lecture rooms. The launch also has been remodelled, and will be run by steam, instead of naphtha.

Copies of the map completed last year may be obtained of C. H. Paige, 114 Pierce Hall. The map includes all of Squam Lake and the roads between Chick's Corner, Meredith, and Ashland.

Pen and Brush Club.

The Pen and Brush Club was founded in 1894 by members of the Class of 1896, its object being to promote social intercourse among its members and to encourage a keener interest in matters relating to architecture and the other fine arts. The members are drawn from the department of Architecture

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at the University but other men in the University deeply interested in art and architecture are also eligible. Any student in the department who does promising work in his first year may be elected a member during that year while others, who are upper classmen, are elected from time to time. The dues are $5.00 per year. There is no initiation fee, candidates for membership being required to undergo an initiation which usually takes the form of making a drawing, painting, or something similar.

Interest in architecture is encouraged, among other ways, by means of a series of lectures by men distinguished in the profession and by sketch and finished drawing competitions among the members of the club, liberal cash prizes being awarded. The Club holds also, during the latter part of each college year, an exhibition of original work of club members. The exhibits are of two classes, namely Architectural Design, and miscellaneous drawings, paintings, etc. Medals are awarded to the winners in each class. Mr. H. D. Whitfield, '98, of New York City, a former president of the club, has recently presented a bronze medal to be competed for annually by members of the club. The annual dinner generally brings together, not only the present members of the club but past members as well.

The Department of Architecture has given to the club the use of a small room in Nelson Robinson Jr. Hall where the meetings are held. Among the periodicals there for the use of members are: The International Studio, Masters in Art, Jugend, the Harvard Crimson and the Harvard Lampoon.

Architectural Notes.

It was the privilege of many who were interested in architecture and landscape architecture to listen recently to Mr. Frank Miles Day of Philadelphia, a prominent architect, who spoke in Robinson Hall, under the auspices of the Pen and Brush Club, on the question of Municipal Improvements in this country.

The cities of St. Louis, Minneapolis and St. Paul, Cleveland, Buffalo, Washington and New York came under consideration

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and the masterly solution by different architects of the problems in the placing of the public buildings and the developing of the park systems were shown by lantern slides and explained.

The "programme" at Cleveland was particularly impressive in its scope, involving not only the placing of the public buildings but a railroad terminal and accommodation for some of the largest shipping business in the country if not in the world.

It was inspiring to hear that this development was the result of the splendid civic common sense of the public authorities influenced by the practical idealism of the architects. Members of the architectural club in that city it is understood first made the suggestion and worked out the schemes, one of which was later developed.

The case of Buffalo is almost equally interesting. It involves the question of railroad and lake transportation and the public building question in a lesser degree than at Cleveland. The railroad accommodations, the station itself and its location, in Buffalo have of late years been for the public, very inadequate. The present plan solves the question of railroad convenience by making the station central and commodious and at the same time it opens in an ideal way the focal point of the city to the fine lake front and gives to the public buildings a dignified approach.

Mr. Day also showed illustrations of the plan of the commission appointed four years ago by Congress, for the development of the city of Washington, and showed how in spite of opposition the scheme was being followed in the placing of the recent new buildings. Drawings for the new Pennsylvania Railroad terminal were shown and in this connection the studies for the new stations in New York were also exhibited.

They seemed to be among the largest and in a way the most difficult programmes that as yet American architects have had to follow and their size and scale perhaps give one a better idea of the practical requirements of our civilization than even the great office buildings and hotels. It is interesting to see in the working out of all these great problems the interdependence of the architect and engineer.

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Tantalum Lamps.

The Electrical Engineering Department has recently been testing some of the new tantalum incandescent lamps that have aroused so much attention. The lamps resemble in external appearance the ordinary 16 c. p. Edison incandescent lamps, except that they are a little broader. Internally, the filament, instead of forming a loop or a pair of loops, is run up and down in a zigzag path over a cylinder form, like the binding cord of a bass drum. The bends of the filament are loosely supported by radial steel wires which project from a central glass stem. There are eleven of these radial supporting wires, like umbrella ribs, at the top of the drum and eleven more at the bottom. The tantalum filament, strung up and down on these supports is about 65 cms. long and is 0.05 mm. in diameter, for a 110-volt-25-hefner lamp (22 horizontal British candles) consuming about 42.5 watts or 1.7 watts per hefner. The ends of the filament are fastened to steel wires, which lead outside to the lamp-base through short platinum sealing-in wires in the usual manner. The candle-power of the lamp is nearly uniform in all directions perpendicular to the axis, owing to the symmetrical disposition of the filament.

In a carbon lamp, the resistance of the filament, when hot, is only about half that when cold. But in the tantalum lamp, the resistance hot is five or six times as great as the resistance cold.

The life time of these lamps is stated by the makers in Germany to be about the same as that of the ordinary carbon lamp. If, therefore, these new tantalum lamps cost no more than carbon lamps, and consume less than 2 watts per candle instead of the present 3 or 3.5 watts per candle, with the same duration of life, we may expect metal filaments to supersede the carbon-filaments.

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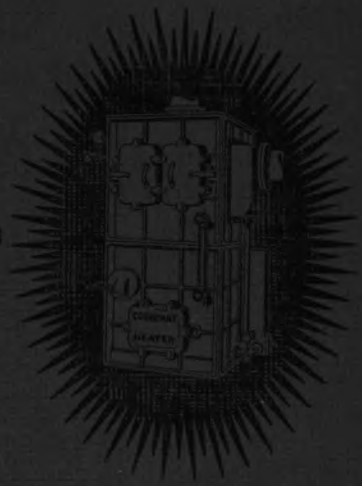

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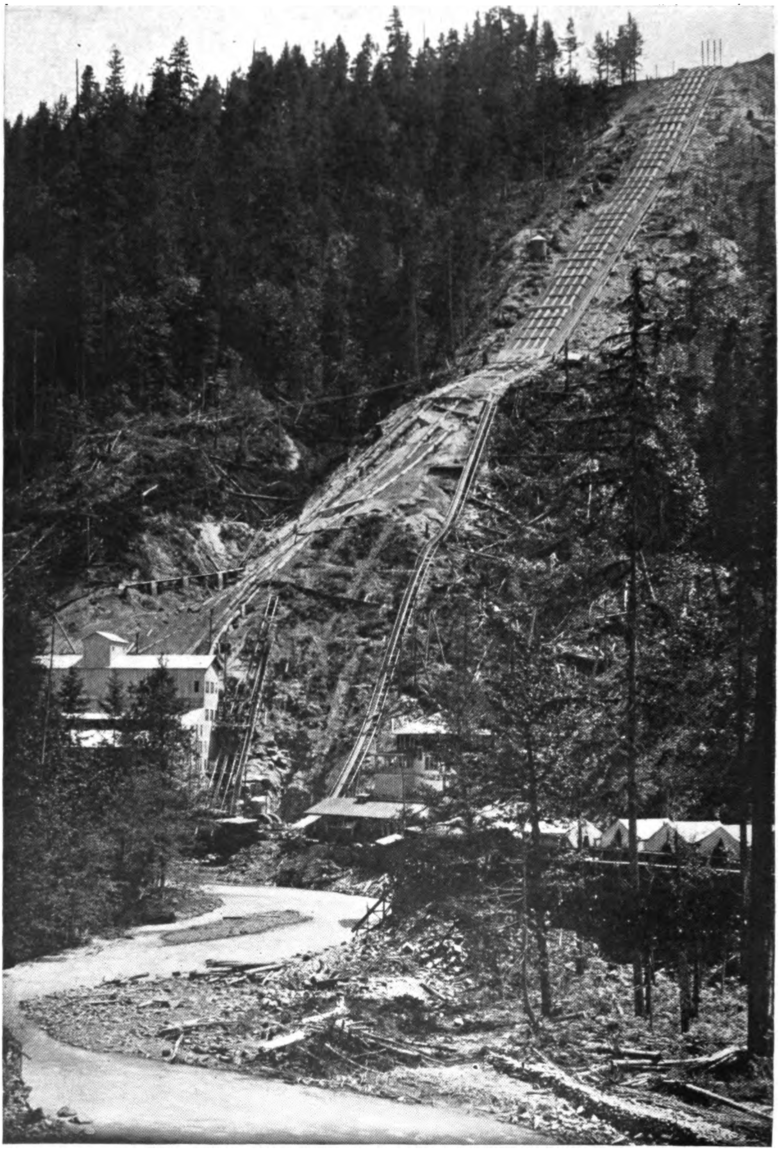

POWER STATION AND PENSTOCKS.

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THE PUYALLUP RIVER WATER POWER DEVELOPMENT AND HIGH TENSION TRANSMISSION TO SEATTLE AND TACOMA, WASHINGTON.*

By J. F. Vaughan, '95.

(Read before the Harvard Engineering Society, Feb. 20, 1905.)

At the last meeting of the Institute of Electrical Engineers in New York, Mr. Mershon read a paper which is likely to become historic. He treated the subject in the nature of a prophecy, indicating by a mathematical discussion of the commercial problem the distance to which electric power might be economically transmitted in the future. It is interesting to study the problems and limitations of the present state of the art, and to note the simultaneous working out of the high head hydraulic problems so intimately connected with work of this kind in the West. To illustrate and to suggest material for discussion, a description of the Puyallup system recently put in operation in the State of Washington may be of interest.

To begin with, the natural conditions of this power are unusual. Examining the map, we see how the prevailing winds laden with moisture from the Japanese current off the coast, blow inland, first over rich lowlands near the coast, next through a densely wooded plateau, almost free from snow the year round, and finally striking the glacial peak of Mt. Rainier, the highest mountain in the United States (Alaska excepted), ris-

* From a lecture to the Local Section A. I. E. E.

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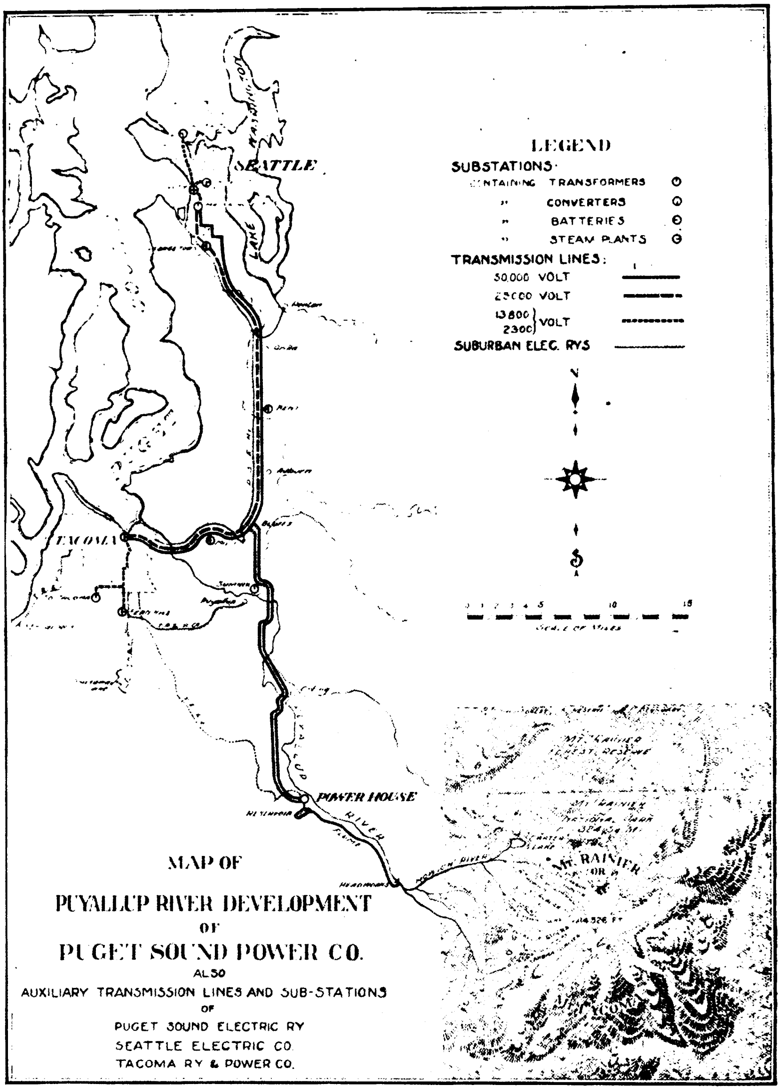

MAP OF
PUYALLUP RIVER DEVELOPMENT
OF
PUGET SOUND POWER CO.
ALSO
AUXILIARY TRANSMISSION LINES AND SUB-STATIONS
OF
PUGET SOUND ELECTRIC RY
SEATTLE ELECTRIC CO.
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ing 14,456 feet above the sea, and covered with perpetual snow and ice. The result is, in winter, a heavy precipitation and run-off from the plateau and storage on the frozen mountain; and, in summer, a second supply to the mountain streams from the rapid melting of the mountain glaciers. The value of this summer flow to those familiar with the ordinary Western streams which run bottom up at this season, as they say, will be evident. The precipitation on the mountain is estimated at 140 in., annual.

The Puyallup River, draining five glaciers and running through the timbered plateau to the lowlands, provides a water power of the above characteristics. The rapidly growing commercial centers of Seattle and Tacoma on the coast, about 50 and 30 miles respectively from the junction of this river with the Mowich, a river of the same kind, furnish a profitable market for the power. This power the Puget Sound Power Company has developed to the extent of 20,000 h. p., making provision for an extension to double that amount.

Briefly outlining the system: —

Water is taken from the Puyallup River below its junction with the Mowich; is then carried by a flume along the canon sides to a reservoir on the tableland, and then dropped through steel pipes to the water wheels in the power station on the bank of the river deep down in the bottom of the canon. Current from generators driven by the water wheels is transmitted at 55,000 volts to Seattle and Tacoma for operating the local street railway and lighting and power systems, to the substations of the interurban third rail road between the cities, and to various towns in the neighborhood for lighting, power and miscellaneous uses.

Dam and Intake.

From the nature of the river, which, in freshet, brings down sand, boulders, and other debris, a deflecting weir, in the form of a low A-shaped timber crib faced with timber, only high enough to deflect the water into the flume without offering

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DAM AND FLUME INTAKE.

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obstruction to freshets, was built across the river, and cut slightly away at the crest on the flume side to maintain a scour on that side of the river. During the first freshet the river covered the up-stream with boulders, graded down-stream into smaller stone, pebbles, gravel, and finally sand near the crest, leaving a clean channel across the entrance of the flume intake. This intake is of concrete masonry 63 feet long, tapering to the flume where a radial gate operated by water counterbalance may be operated from the attendant's cottage on the hillside above.

Flume.

The flume, laid with a hydraulic grade of 7.5 feet to the mile, follows the river along the canon sides like a mountain railway. It is of timber frames 8 ft. by 8 ft. on bents heavy enough to carry the construction trains. For the present development, it is planked to a height of 5 feet only. The only peculiar features of the flume are the smoothness of the curves and the precautions taken to pass off the finer glacial and river sand which, if allowed to reach the water wheels, cuts the nozzles and buckets like a sand blast. Several devices are used, as, for instance, deep pockets built into the bottom of the flume at intervals and provided with baffles to prevent churning and blow-offs to discharge the sand; herring-bone shaped plates or knife edges called undercurrents on the bottom of the flume, the apexes pointing down stream and provided with discharge holes in the flume bottom. To provide for repairs, the flume is divided into sections by needle gates and spillways at various points, and to regulate the height of the reservoir a large spillway at the entrance to pass off surplus water.

Reservoir.

The reservoir, on the plateau, at an elevation of nearly 900 feet above the power station, is of sufficient capacity to run the plant at full load for 8 hours. The fine hardpan, or boulder clay, forming the plateau, required dynamite before a steam

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RESERVOIR SHOWING FLUME AND FOREBAY.

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shovel could get hold of it. The excavated material proved to be ideal fill for the embankment built on the lower side of the site, puddling to a soupy consistency, and in a few hours taking a set like natural cement.

The flume enters one end of the reservoir passing to a concrete basin in front of the forebay to permit emptying and cleaning of the reservoir without interruption to the plant. The basin serves to prevent air from entering the pipes and making trouble. From this forebay, which is of concrete, provided with a gate for each pipe line, the nine pipes, one for each unit and one for two exciters, drop precipitately into the canon producing an effective head of 870 odd feet in a distance of about 1700. Although this head is less than half that of one of the California plants, one can imagine, nevertheless, the precautions necessary to handle safely such a column of water, which, in each main pipe, represents a kinetic energy of about 1,000,000 ft. lbs.

Each of the main pipes is of riveted boiler plate 4 ft. in diameter and $\frac{1}{4}$ in. thick at the upper end, and tapering to a diameter of 3 ft. and increasing to a thickness of $\frac{3}{4}$ in. at the power station. The use of relief valves was considered, but abandoned as a possible danger in case of the failure of the valves to operate properly. The weakest part of the line is the nozzle tips which would probably blow out in case of excessive water hammer. The pipe lines are anchored at intervals by massive concrete abutments designed to also drain away all surface water. For further security, the pipes are protected by backfilling of earth planted with quick-growing vegetation.

Power Station.

On a bench blasted out of the rock on the edge of the river is built the power station, the generating house of concrete, brick and steel below and the transformer and switch house adjoining and over the penstocks on the hillside.

The generating house, at present 266 feet long by 100 feet wide, contains four 3500 kw., 2300 volt, 3-phase generators of

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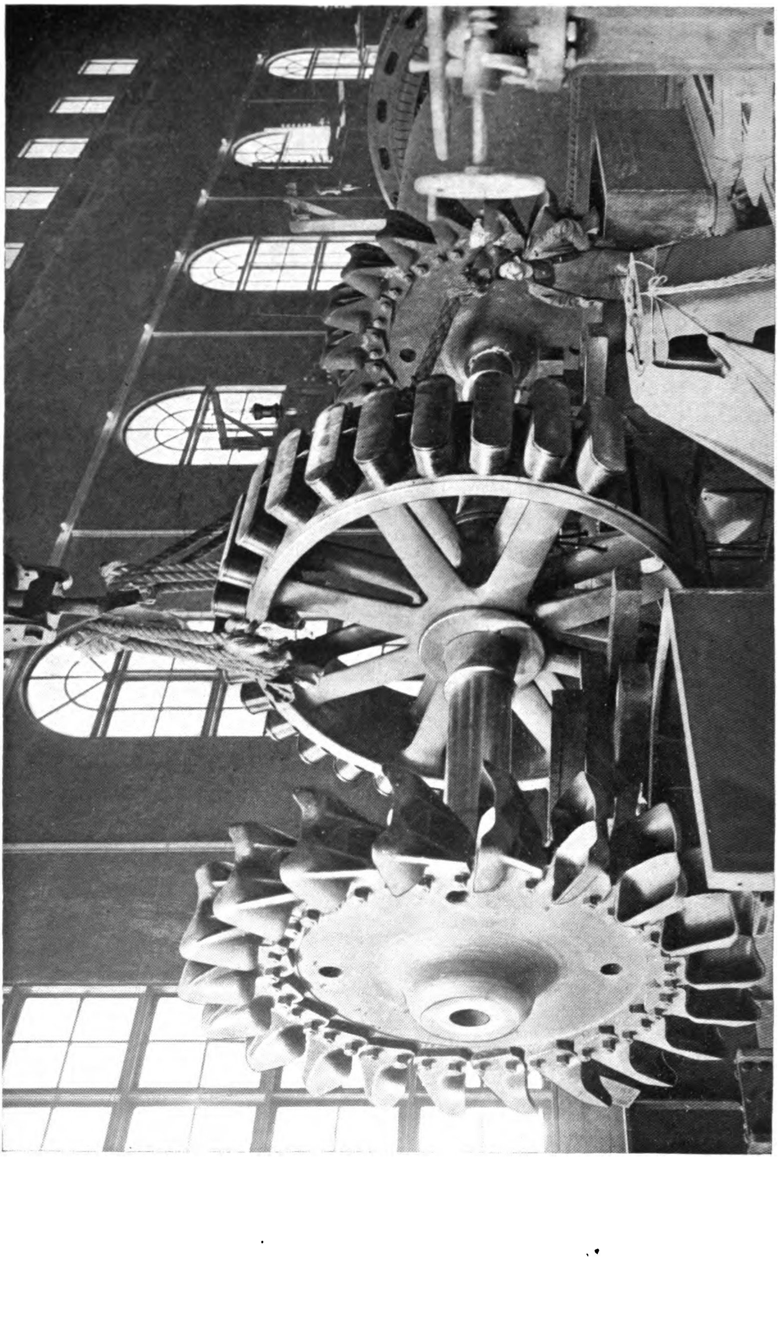

GENERATING UNIT DURING CONSTRUCTION.

the revolving field type, each driven by a pair of Pelton water wheels of 7500 h. p. capacity, and two 150 kw., 125 volt exciters. The completed station will provide for four additional generators and a motor driven exciter. In addition, a single Pelton wheel on each exciter has direct coupled to it an induction motor connected permanently across the 2300 volt busses. The purpose of this motor is to provide a relay in case the wheel nozzle clogs or the wheel is otherwise disabled, and also acts as a regulator drawing current when the speed falls below normal, and absorbing power as a generator on overspeed.

The weight and speed of the rotating parts of the generating unit, — two overhung wheels of about 10 feet diameter, mounted one on each end of the shaft with the revolving field between, weighing about 35 tons, running at 225 r. p. m., — present an interesting mechanical problem. The two large bearings are ring oiling, fed by a motor driven centrifugal pump and gravity system, and, for starting, with oil from a force pump at sufficient pressure to lift the shaft off its seats. The bearings are also provided with circulating water and thermostat alarms on the switchboard.

Water is brought to the wheels from each penstock through two nozzles of the needle type, arranged for automatic deflection by a Lombard governor for speed control, the operation of the needles being for economic adjustment of the discharge to the load on the machine. Provision is made for automatically adjusting the needles to the load by a secondary action of the governor on an electric motor geared to the needle stems, a novel combination which promises well. Each nozzle is also provided with a motor operated gate valve. The main and exciter units are started, stopped, and controlled from the main switchboard.

The transformer and switching house, forming the up-hill half of the station, is built with the step-up transformers at the bottom opposite the generator, the low tension wiring and switches on the floor directly above, the high tension buses and switches still higher up, and above all the wire tower, from

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which the transmission lines lead and containing the lightning arresters.

The scheme of electrical connections is: —

Four generators connected through oil switches to either of two sets of low tension buses; three sets of step-up transformers similarly connected to these buses on the other side. In the same way the high tension side of each bank of transformers will be connected through high tension oil switches to a duplicate set of 55,000 volt buses, each bus being connected through an oil switch to one of the transmission lines. One set of high tension buses only is in place, sectionalized by oil switches for the present, one section corresponding to each bank of transformers. Thus, we have in the completed plan a means of combining generators, transformers and lines into different groups, or of dividing the station into separate units from transmission lines through to generators. In testing a faulty line, one generator and transformer bank may be separated for the purpose, as in case of burning out short circuits or grounds. This plant, operating the greater part of the time without the aid of other sources of power on the line is necessarily more elaborate in switching apparatus than many of the other Western plants which are paralleled with one or more other plants at all times. To minimize chances of interruption from short circuits on the system, the line transformer and generator oil switches are provided with time limit relays, the time element being graded from the shortest on the lines to the longest on the generators.

Synchronizing is done on the low tension side.

The transformers are arranged in three banks of three each, connected, Δ Δ, each bank being of the capacity of two generators, thus giving 50% spare capacity in the third bank. The transformers are of the usual oil insulated water cooled type. In erecting, special care was taken in testing the oil for breakdown resistance, in drying out traces of water, and in drawing it into the cases under a vacuum of 26 in., followed by a second baking out in the transformer case before putting into service. Static dischargers in the form of shunt lightning arresters on

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the low tension side are used to protect the transformers against unusual disturbances.

The fire hazard is reduced to a minimum by setting each bank of transformers in a separate concrete cell with automatic fire doors, and piping to drain off the oil into the river in an emergency. An internal explosion of oil will be resisted by the strength of the boiler plate casing of the transformer, while a fire from oil thrown out will be smothered in its own products of combustion by the closing of the fire door.

Both high and low tension wiring is largely in fireproof cell work, and all the oil switches are motor driven and operated from the main switchboard on the gallery at the end of the generating room.

The switchboard is of the remote control type arranged in the form of a crescent on the gallery of the generating room as already mentioned. This places the control of all the station apparatus, transformers, transmission lines and ultimately the head gates at the reservoir under the control of one attendant, who, in addition to his direct view of the indicating and recording instruments connected with the station apparatus and the lines, and a water level indicator connected with the reservoir, keeps in touch by telephone with the operator at the headworks, reservoir and sub-stations, and with the patrolmen on the flume and transmission lines. In addition to the usual indicating and integrating instruments the switchboard is provided with the General Electric Company's new type of curve drawing instruments, keeping a continuous record of current, voltage and station output. Similar records are kept in the principal substations.

Transmission Line.

The transmission system is in duplicate throughout.

From the power house two parallel transmission lines run a distance of 22 miles to Bluffs, a station on the line of the Puget Sound Electric Railway, 9 miles from Tacoma and 25 miles from Seattle. From Bluffs one line runs for a great part paral-

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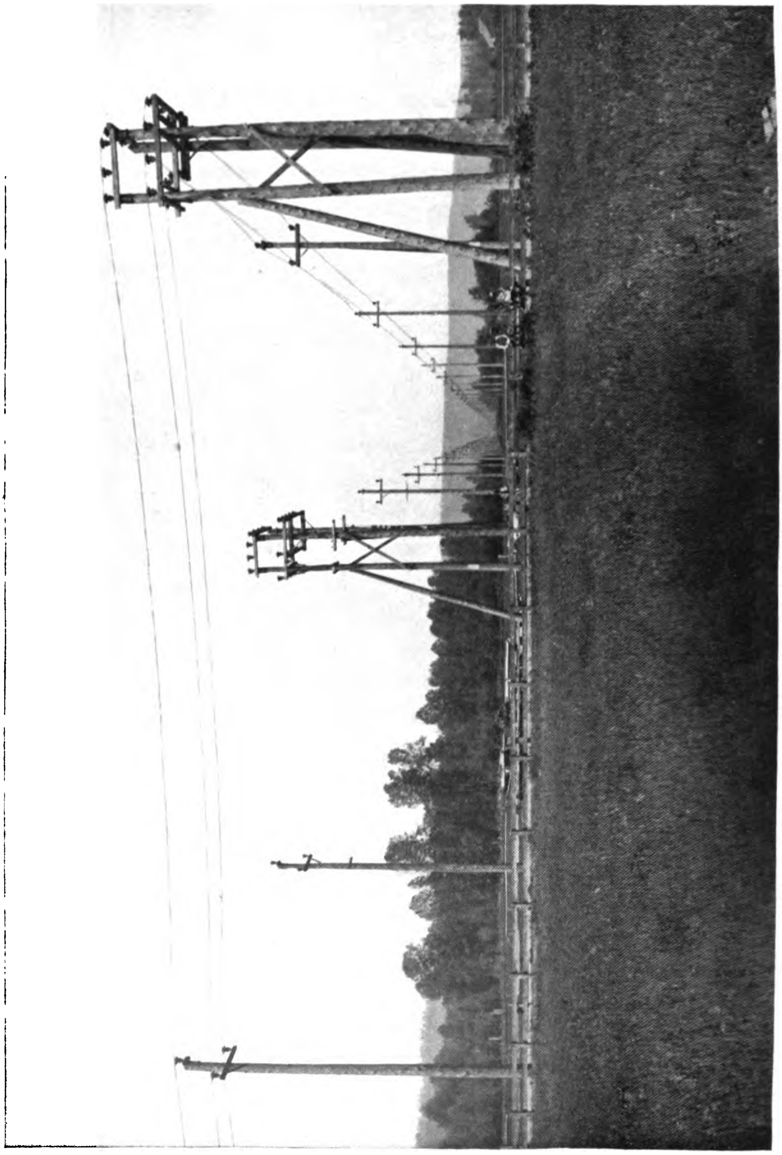

RIGHT ANGLE TURN IN TRANSMISSION LINE.

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lel to the transmission line of the Puget Sound Electric Railway, to Seattle, and one to Tacoma, also parallel to the transmission line of the Puget Sound Electric Railway.

The transmission line of the Puget Sound Electric Railway is at present operating at 27,000 volts; but the line is designed for operation at double this voltage, so that, when this line is changed over to a 55,000 volt basis, there will be two complete and independent pole lines from the power house to Seattle and Tacoma. At Bluffs there are erected junction pole switches, by which the two transmission lines may be cut through independently, one to Seattle and one to Tacoma, or both lines put in multiple, or any section isolated without interfering with the operation of the other sections. The wires are arranged on a 72 in. equilateral triangle, one 3-phase line per pole line.

The transmission line is necessarily the most exposed and weakest part of the system, and insulation the weakest point of the line. Hence, every effort was made to produce a rigid construction and especially a reliable insulator, and the results so far reported, — none failing from electrical or mechanical weakness,— are certainly very gratifying. The insulators are of special design, and were submitted to puncture test before shipping and again after assembling and before putting up. Sample insulators, made up to select from several designs, gave in this case under an artificial precipitation of $\frac{1}{2}$ in. per minute at an angle of 30° from the horizontal an arc-over voltage of between 90,000 and 100,000 volts, which means in operation a factor of safety of over 3. The mechanical strength tested to a wire pull of about 4,000 lbs. and the behavior of the insulator under electrostatic charge was very satisfactory.

There has been considerable trouble on the coast from burning and digesting of wooden pins exposed to salt fog. For this reason one of the lines was fitted with galvanized malleable iron throughout, and the others with eucalyptus pins waterproofed by boiling in linseed oil. The long span construction using steel windmill towers was considered, but abandoned, partly because it was new and untried, and partly on account of the excellent timber available on the ground for the ordinary con-

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struction. More recent experience has brought out the advantages of this construction and appears to show on the average little difference in cost. The Puyallup lines are transposed, making a third of a turn about every four miles.

The telephone system has already been mentioned. Along the transmission line two wires of No. 10 copper are mounted on double petticoat glass insulators on a cross-arm 7 feet below the main cross-arm. The wires are transposed about every 1200 feet. To avoid accidents to the operators from static induction, — which in the case of one system has produced a difference of potential between wires and grounds of 2,000 volts,— the telephone booths are insulated from the ground. The transposition appears to take care of noise from induction from the transmission line. In order to insure reliability of service this line is supplemented by a line rented from the local telephone company.

Distribution.

In the distribution of current there is little unusual. In Seattle and Tacoma banks of pairs of 2,000 kw., transformers Scott connected, step-down the current from 50,000 volt, 3-phase, to 13,800 volt, 3-phase, or 2,300 volt, 2-phase, for local distribution, or for still further reduction and transformation to operate a. c. and d. c. lighting circuits, motor generators for railway and battery work etc. As the system grows, an effort will be made to have sufficient synchronous apparatus in service to properly control the power factor.

In closing, a few remarks on the results obtained in operation will be of interest.

With the aid of a log swung from a cable in the current of the river at the headworks, it has been found possible to keep the channel free and in its proper position. While there was some trouble from the cutting of nozzles and wheel buckets from sand brought down when the system was first started, the sand devices appear to be giving fairly good results to-day. The glacial silt which is so fine as to remain in suspension in

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quiet water for many hours, is not sharp enough to more than polish the metal surface.

The loss of head in the pen-stocks, although figuring about 12 ft. when the pen-stocks are running full capacity, is reported to be slightly less. As the shortest time in which a pipe line can be wholly shut off at present is 30 minutes, the gauges show no effect of water hammer.

In regard to the transmission line. It is a satisfaction to state that there have been no electrical failures of any of the insulators due to puncture or excessive leakage. A number of insulators have been changed on account of breakage from shooting or throwing stones; also, during a forest fire before the brush was cleared away from the line right of way, several insulators were cracked by heat. Although insulators damaged by shooting or otherwise have been badly broken,— in one case, in fact, half a top being destroyed,— the lines have shown no indications of trouble. Experience with the iron and wooden pins indicates that the cracking of an insulator throughout means in dry weather practically a short circuit on the iron pin and little trouble on the wooden pin. In wet weather, naturally, there is little difference. There has been no trouble from burning or other failure of pins due to leakage. The greater strength of the iron pin gives it preference over the wooden pin.

Considerable trouble was expected in the operation of the telephone line, but although the line from the power house down is mounted directly on a cross-arm on one of the transmission pole lines and is connected to the telephone system of the Interurban Railway and through an oil insulated repeating coil to the local telephone service in Seattle,— which means that part of the line is operated under a 55,000 volt line and part under a 30,000 volt line for a time fed from a different source of power,— there is in general less disturbance in the telephones even when talking with the Seattle service than is often found on the lines of the local service itself. Tests for electrostatic induction from the transmission line indicate a difference of potential between the telephone wires and ground of not over 150 volts.

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The charging current of one line from the power station to Seattle is about 900 k. v. a., and on the other line to Tacoma about 750 k. v. a., or approximately 19 k. v. a. per mile. The power factor swings about unity, above or below according to the load on the system. On the present load of the plant, amounting to a demand of between 12,000 and 13,000 kw., the daily load factor approaches 70%, which figure by the sale of wholesale power is expected to materially increase. The old steam stations in Seattle and Tacoma are operated during the extreme height of the daily peak and are held in reserve as relays in case of trouble.

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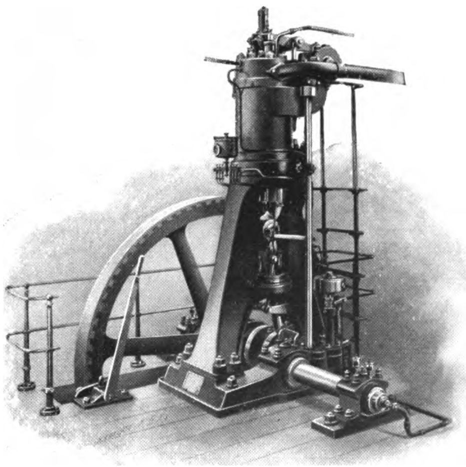
THE AMERICAN DIESEL ENGINE.

By E. D. Meier.

On June 16th, 1897, Mr. Rudolf Diesel, an eminent engineer of Munich, Germany, read a paper before the National Society of German Engineers about an internal combustion engine he had invented, which approximated in practice the ideal cycle of Carnot.

The economic efficiency of his engine was shown to be double that of the best steam engine. He invited all engineers to visit the works at Augsburg to verify his claims by rigid tests.

Engineers from all Europe, and from America responded, and came home convinced and converted. Practical difficulties were indeed predicted and encountered. But in a few years they were successfully overcome, and the engine entered the power market as the most economical of prime movers. But the claims set forth as to the economy of this device were so large



FIRST GERMAN MOTOR, 20 H. P.

and far-reaching that most practical men received them with a shrug of the shoulders. They were, nevertheless, not only true,

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but somewhat under-stated. From the small Diesel motor of twenty B. H. P., which gave these remarkable results, has grown by a natural process of evolution the American Diesel Engine of to-day, at present built in sizes from 75 B. H. P. to 450 B. H. P.

A short explanation of the working of this engine may be opportune.

The Diesel Engine is essentially an oil engine, aud not a gas engine. Gas engines, and previous oil engines, which acted on the gas engine principle, have all in common the explosion of a charge. This charge is a mixture of a given quantity of gas, or of a given quantity of oil vaporized so as to act as a gas during the process, combined with a quantity of air varying from seven to eleven times the volume of the gas or vapor. It was well known that some previous compression would add to the economic results of the explosive action. But in all cases the power was obtained by an explosion, which, from the moment of ignition, was beyond control of the operator, or of the governing mechanism of the engine. This fact limited the efficiency of all governing devices which could be applied, and troubles with the ignitor caused other irregularities, so that, even where local conditions made the gas engine (or vaporized oil engine) the worthy competitor of the steam engine, uncertainties of its operation threw doubt on the wisdom of the substitution.

Furthermore, a cheap gas, necessitating the installation of a large and cumbersome producer plant, was the only escape from such costly fuels as gasoline or kerosene.

The Diesel makes the use of the cheapest liquid fuel, such as crude oil, fuel oil and distillates, possible. To these, recent developments have added the waste product from gas works, known as light water gas tar.

The Diesel Engine works on an entirely new principle. First, it dispenses with the so-called charge or mixture. Its cycle is the same as the gas engine, the well known Otto cycle. There its similarity with the gas engine ends absolutely; in everything else it follows the precedent of the steam engine.

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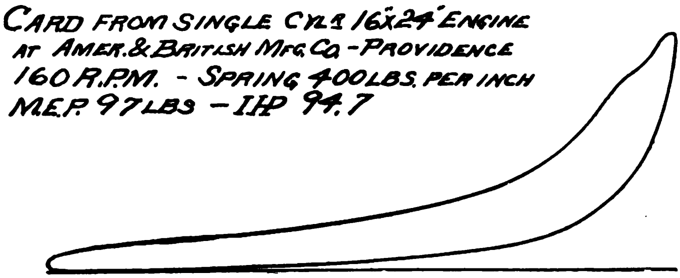
Its first stroke is a suction stroke, drawing in a cylinder full of pure, clean air; on the second stroke, it compresses this to a degree and consequent temperature sufficient to ignite any fuel which may be injected into it; at the beginning of the third stroke, a small quantity of fuel oil is injected into this red-hot air as a spray by a jet of highly compressed air, and thus in a completely atomized state the fuel meets and mixes with the hot compressed air in the cylinder, burning completely, and during a period of time exactly regulated by the governing mechanism of the engine, generally through one tenth part of the stroke, subsequent to which the stroke is finished by the expansion of the burnt products; the fourth stroke discharges



these products of combustion, and leaves the cylinder empty and ready for another suction stroke.

It is evident that the work expended in compressing the cylinder volume of pure air is given off again to the shaft of the engine during the combustion or motor stroke, so that the loss is simply the frictional loss during the compression stroke.

This simple process, absolutely new and original with Diesel, has enabled him to accomplish with one half pint of common crude or fuel oil as much as the explosive engine does with a full pint of the much more expensive gasoline.

A recent comparison of results, extending over a period of regular daily service of six weeks, has shown the consequent economy of the Diesel Engine over a first class gasoline engine, which it displaced, of 600 per cent.

The modest statements set forth some years ago by the promoters of the Diesel Engine, and covered by absolute and bind-

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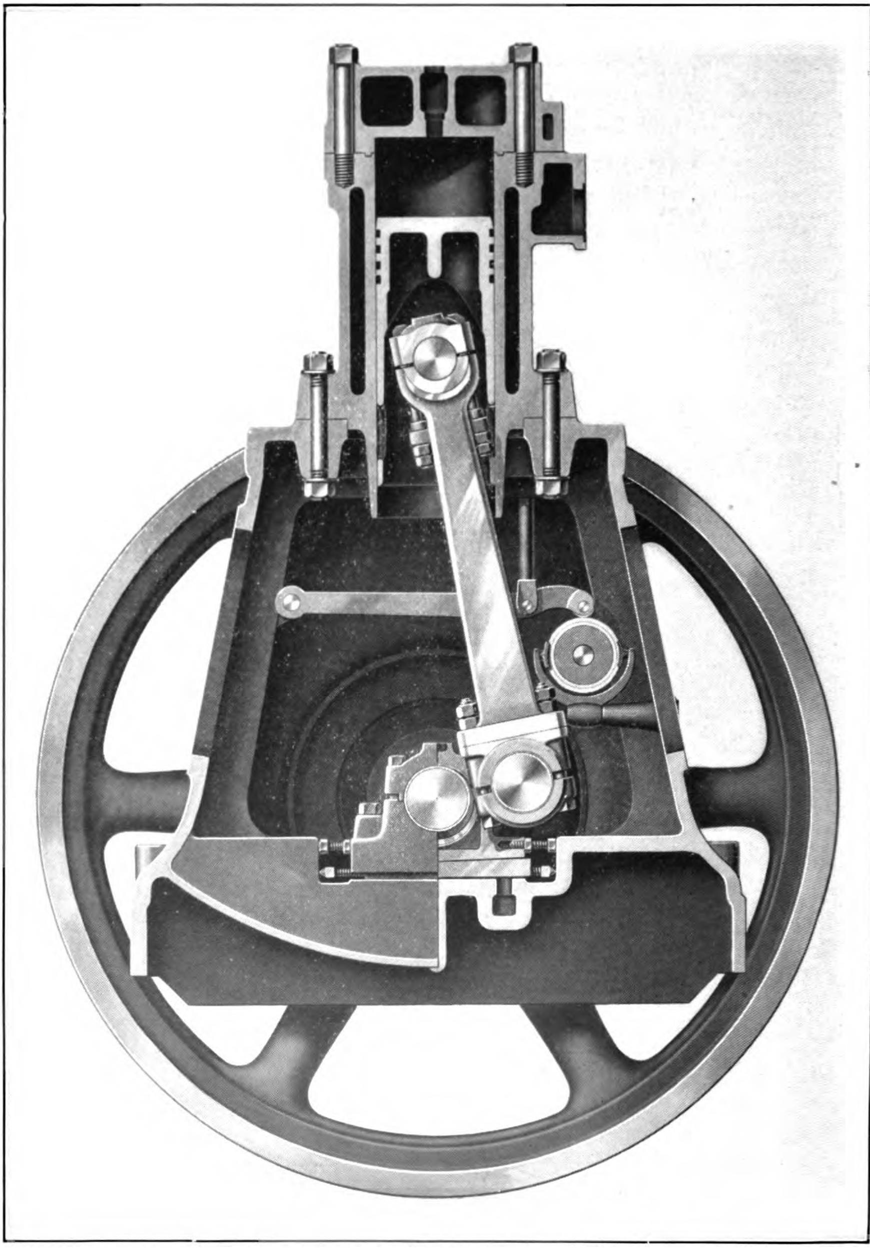

SECTIONAL VIEW, DIESEL ENGINE.

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ing guarantees, are that 100 B. H. P. hours measured in the crank shaft of the engine will require not exceeding eight gallons of crude oil or fuel oil when the engine is running at or near its rated capacity, nor more than nine and a half when at or near half-load.

The regulation in the Diesel Engine is not dependent on hit or miss, but can be followed up or down the scale as closely as in a steam engine. In the latter it is a question of cutting off more or less from a pretty large volume of steam at each stroke; in the Diesel Engine it is the finer one of cutting off a more or less minute quantity of oil from the small volume delivered by the fuel pump at each stroke. It is accomplished by direct action of the governor on the suction valve of the fuel pump, which is held open during a greater or less portion of the pressure stroke, and thus the pump delivers the exact quantity of oil required during each motor stroke of the engine. While the mechanism is necessarily smaller, and more delicate than in the steam engine, it also requires less power, and its effect is more immediate.

In a compound steam engine the volume of steam left in the high pressure cylinder at the point of cut-off must be used in the next stroke of the low pressure cylinder, whether at the time more or less would be the proper quantity for that stroke. In the Diesel Engine the regulation acts on each cylinder just at the time and in the exact quantity then required.

There remains only the drawback common to all four cycle engines, — that there is but one motor stroke for each two revolutions. For electric light work, triple cylinder engines and heavier fly-wheels successfully overcome this, while for electric railway work resort is had to still larger fly-wheels and six cylinders by coupling two triple cylinder engines to the two ends of the same dynamo shaft.

As for the accessibility, reliability and durability of the engine, four years of experimental work has placed these fully on a par with the best steam engine practice, and since then, two years, in some cases three years, of continuous service by a number of Diesel engines of the New American type, give additional guarantees.

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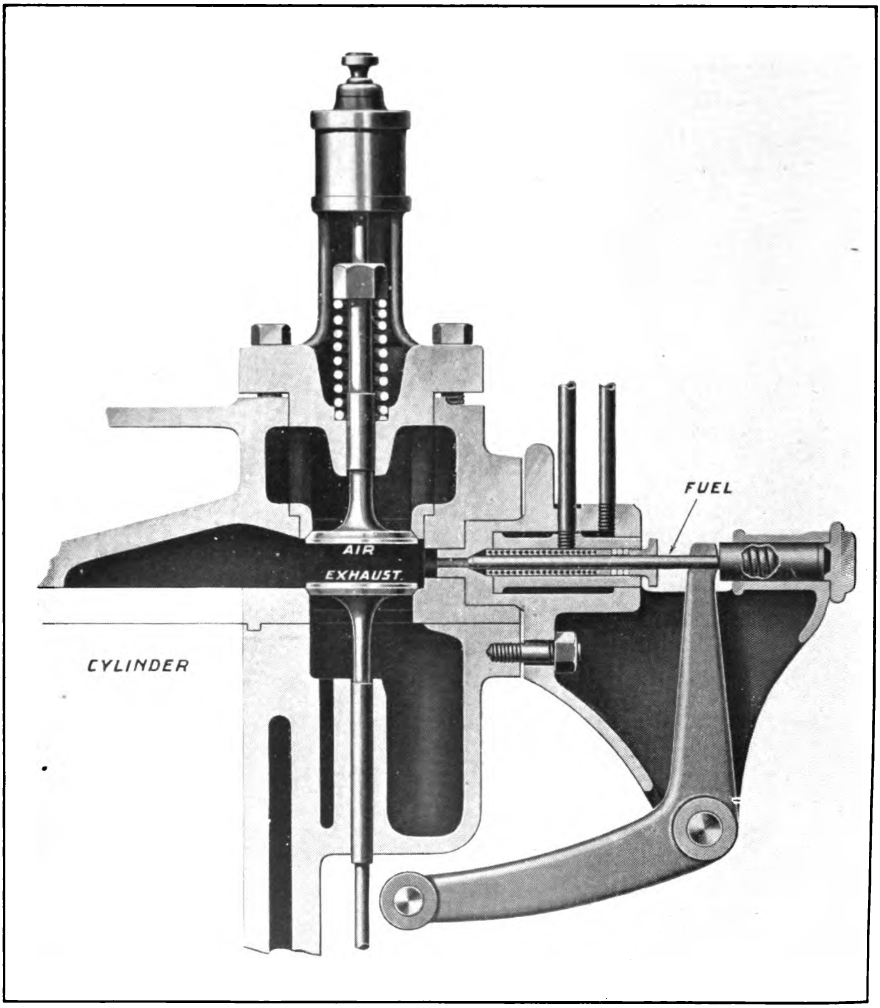
I have heretofore given a graphical comparison of the thermal efficiencies of a justly celebrated steam engine, that designed by Leavitt, for the Louisville Water Works, of Rankine's



ADMISSION VALVE, DIESEL ENGINE.

ideal steam engine and of the Diesel engine. It is so instructive that I repeat it here.

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Rankine first proposed this ideal cycle on January 17, 1854, and Clausius described the same cycle in 1856, quite independently of Rankine. In short, the Rankine cycle takes in all the usual activities of the steam engine, but takes account only of those losses which are in their very nature inseparable from the cycle. All those vexatious and costly losses which even the best practice does not now, nor ever can, eliminate from the problem, and which may be classed under the general heads of "radiation" and "friction," are in this ideal cycle considered as non-existent.

Capt. R. H. Sankey, of the British Institution of Civil Engineers, originated this method of comparison by likening the flow of heat to that of a river, with its confluents and affluents. He made his comparison from an equal output in effective work. This I have changed, for the purpose of better comparison in this case, by beginning with an equal expenditure in heat units at the beginning of the cycle, thus showing the difference in the output,— in place of in the total expenditure of heat.

In the case of the Diesel engine I start also with the same total expenditure in heat, and trace the flow of this "broad river of heat" through the entire cycle, showing the losses as actually found from a number of tests made on a 20 H. P. Diesel motor at New York. Since then larger units have shown gradual increase in efficiency.

The first diagram (p. 100) shows the reproduction of Capt. Sankey's original graphic representation of the actual results obtained during the test of the Leavitt pumping engine at Louisville.

As Prof. Thurston says, "This is an exceptionally good illustration of thermo-dynamic action, and the wastes are very much smaller than are commonly observed in the operation of even good classes of steam engines." The entire river of heat, with a discharge of 183,600 heat units per minute, flows from the fire grate. To the right is seen the loss by radiation in the boiler itself. But about three fourths of the entire flow turns toward the steam pipe. Considerably over one fifth, however, flows toward the left, toward the economizer, where it loses again by radiation, but is re-inforced by a brook coming from

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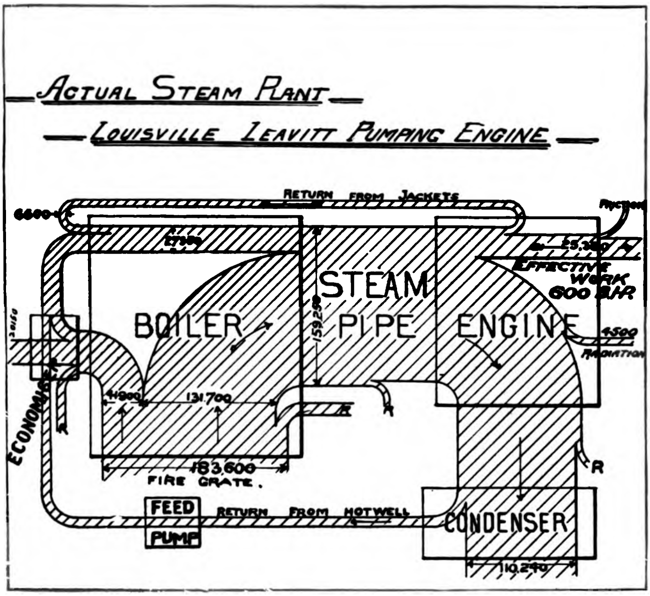
the hot well through the feed pump, and is further joined by a rivulet of returned heat from the jacket water, altogether forming a tributary of no mean size, joining the stream flowing into the steam pipe. Here again, at the bottom, the small rivulet escapes through radiation, but the main body passes on into the engine, where we have the smaller losses by the stream which runs into the jackets, the other which represents the mechanical friction in the engine, and the third, the radiation. By far the larger stream, however, is lost in the exhaust steam. In passing through the condenser, however, a small brook is diverted toward the feed pump to again do useful work, as above described. We have then left (in the upper right-hand



corner of the diagram) but the small fraction of 25,390 heat units, or say in effective work 600 brake horse power, which represents only 13.83 per cent. of the total which is given to the engine; or, as it is customarily expressed, this most excellent engine plant, representing the highest development of modern steam engine practice, has realized an absolute efficiency of only 13.83 per cent.

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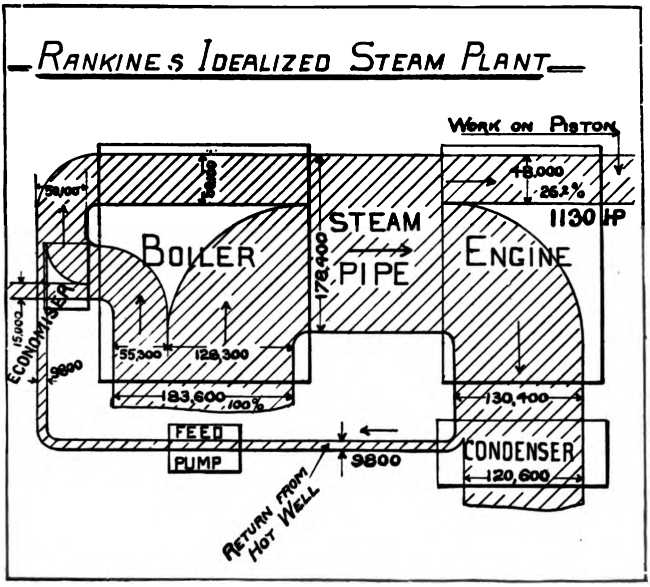
The second diagram shows the same plant running on Rankine's ideal cycle. In this friction and radiation are swept away by one happy stroke of the imagination. While a larger stream of heat is diverted to the economizer, this has become so effective that it allows only a very small current to escape toward the chimney. In fact, this represents less than eight per cent. of the original volume of flow. From the economizer



a much larger stream, augmented by the brook flowing from the hot well, re-enters the boiler, so that a total of 178,400 heat units enters the steam pipe, more than a quarter of which does useful work on the pistons. But the other three fourths finds its way, as before, to the condenser.

In the stream which finally turns our wheels, we find 48,000 heat units, giving us 1130 H. P., or the absolute efficiency of the Rankinized engine is 26.2 per cent. This then we may consider as the ideal possibility in steam engine practice, toward which we may strive, but which can never be reached, because we cannot dispose of radiation and friction in actual practice as easily as we have done on paper.

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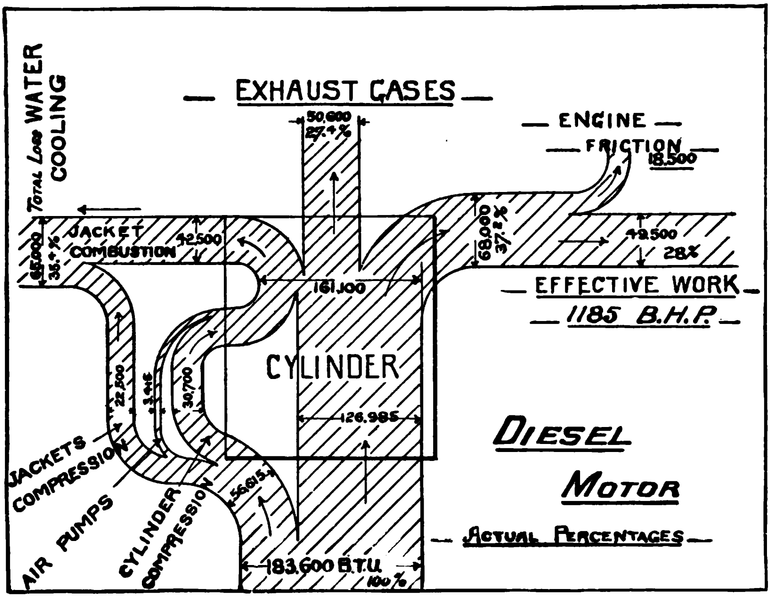
The third diagram shows Capt. Sankey's method applied to the Diesel motor, with the same broad river of heat, having a constant flow of 183,600 B. T. U. per minute. The bulk of this enters the cylinder on its working stroke, but we have before lost more than thirty per cent. from three causes: The one is the actual negative work done in compressing the fresh air of the charge in the main cylinder, and which represents 30,700 B. T. U. A very small stream is the heat expended in compressing air in the air pump, and a third stream aggregating



22,500 B. T. U. represents the loss by cooling, which flows into the jacket water during the period of compression. The two losses first mentioned flow back again into the cylinder during the period of combustion in the working cylinder, so that we find there a total of 161,100 B. T. U. But during combustion we lose again, as shown in the upper left-hand corner, a large stream of heat which flows into the cooling water of the jackets during this period of combustion, so that the final and total loss of heat which has flowed into this cooling water amounts to 35.4 per cent. of the total flow.

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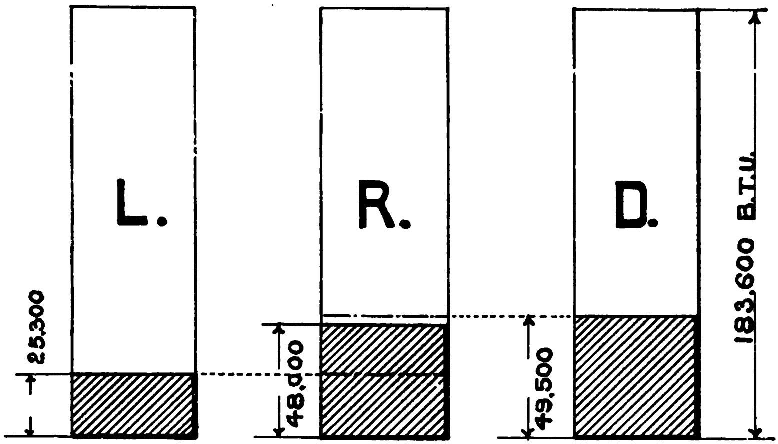
Directly upward is shown a stream of heat, amounting to 27.4 per cent. of the original flow, which we lose in the exhaust gases. To the right a good sized stream, representing 37.2 per cent, flows into indicated work. From this, however, we lose a large amount, *viz.*: 18,500 B. T. U. in engine frictions. Comparing this with the loss shown in the first diagram of the Louisville engine, this stream looks very large. In explanation, however, we must remember that the steam engine has four effective, or motor strokes, to one in the Diesel engine. As the latter has to do its whole work in this one stroke, while the frictions retard it, in all four strokes, it would be entitled to a percentage loss four times as great as that of the steam engine, without being subject to criticism as a mechanically inferior device. Furthermore, the total stream of heat on which this percentage is to be figured is more than double as large as



that which flows into the steam engine. If then this outflow in friction should appear eight times as large in actual quantity as that from the steam engine, it could not be considered abnormal.

Finally, we find a broad stream with a flow of 49,500 B. T. U. in the effective work of the engine, a total of 1185 H. P., or the Diesel engine has shown 28 per cent. absolute efficiency. In our larger units an absolute efficiency of 30 per

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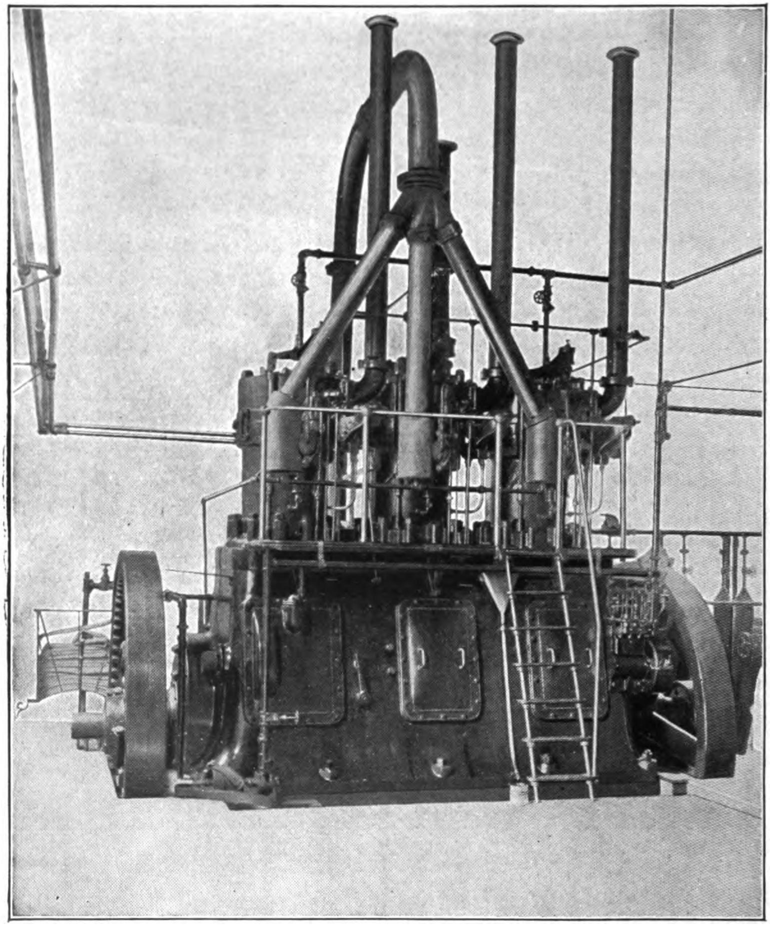
cent. is the standard performance, and is frequently excelled in actual service.

The fourth diagram shows a comparison of the three engines, by a representation of areas simply. In each case the large



225-Horse Power Triple Cylinder Diesel Engines, as installed in the Light and Power Plant of the German Tyrolean Alps at the World's Fair, St. Louis.

rectangle represents the total of 183,600 B. T. U. with which each engine is charged. The smaller shaded portions of the three rectangles show in each case the return made. The rect-

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angles are marked "L" for the Leavitt engine, "R" for the Rankine cycle, and "D" for the actual cycle of the Diesel engine. This shows at a glance that the Diesel engine has in actual practice far outstripped the theoretical possibilities of the steam engine.

Turning again to the third diagram let us examine where further savings can be effected in the Diesel Engine. The engine frictions have been reduced in larger engines, and here is offered a good opportunity for the ingenuity of the designer and the skill of the manufacturer, but after all the field is a rather limited one.

The next loss that through the exhaust gases, can in many cases be very largely reduced by utilizing this heat for heating water or even producing steam for the heating of work-rooms, or for various mechanical purposes. The largest cost, that shown toward the left, as the total loss to the cooling water, can also in many cases, be utilized for the same purposes, and it is simply a question of temperatures and quantities whether these two streams are to be separately utilized or first combined.

Acceptance tests made at Elkhart Lake, Wis., January 24–28, 1905, on a 450 H. P. direct coupled railway unit show consumption of fuel oil of

5.5 gallons per 100 brake horse power hours at full load,
6.5 " " " " " " " " over-load,
6.9 " " " " " " " " $\frac{2}{3}$-load,

A 24 hour service test at Sherman, Texas, on a 225 H. P. direct coupled electric light unit shows a consumption of Texas crude oil of 6.46 gallons per 100 brake H. P. hours at five per cent. over-load. Synchronizing tests made by Mr. W. C. Woodward, E. E., of Providence, on two direct coupled A. C. units of 120 H. P., at Mansfield, Mass., in Dec., 1904, were entirely successful.

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SOME ARCHITECTURAL ELEMENTS.

The Ionic and Corinthian Orders.

By Walter Dana Swan.

The Greek Doric Order, considered in a previous number of this magazine, is studied more for the principles of design which it involves than as an element in one's working vocabulary. It was, to be sure, modified and combined with Etruscan forms, used by the Romans, but it would more properly be considered in connection with the Roman arch order in a separate article. The Ionic and Corinthian orders, on the other hand, are used almost continually by our foremost architects and some examples are given here of their more interesting employment.

Aside from the libraries and university halls, which naturally suggest classical treatment, there is another prominent class of buildings which by their scale and requirements for monumental lintel construction seem almost to demand the employment of the orders to thoroughly express themselves. Without the order or the arch it would be very difficult, if not impossible to give the necessary scale to such structures for the banks and trust companies as those illustrated here.

The development of the "sky scraper" has brought about a reaction which is responsible for many of the interesting buildings of this type, for the banks and trust companies find that their highest financial returns lie in erecting a many storied building in connection with a much lower or single storied structure for the purposes of the bank itself, the light and air in the high building being more of an investment than the many more dark and unrentable offices. In all banks a maximum of light is essential and must be obtained either from skylight or great windows in the walls. These conditions call then for that monumental lintel treatment, the order, or as I have said, the arch, and, given the same span and height, the former cuts off less light than the latter. With regard to this point, the objection has been made

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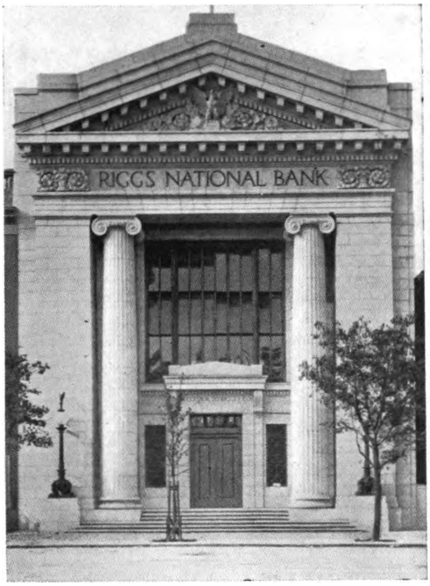
that with modern construction the heavy pier or engaged column is superfluous and cuts off required light on the sides, but if stone is used the wall piers must have the necessary thickness for stability whatever form the piers take, and what cuts off less light than a pier with a circular section? As for appropriateness of design, it seems to many of us that the order is not merely a symbol or expression of Greek or Roman life, but is a most satisfactory design for a pier. It is a scheme contributed to the art of building by the ancients and used (or abused) by



THE RIGGS NATIONAL BANK, WASHINGTON, D. C.
York and Sawyer, Architects.

the building world ever since, according to the amount of right feeling or knowledge of principles which the designer may have had. We are beginning to see the orders in the right light. They are not the foundation of architectural design or of architectural education, but they are important details in both, and the best examples of them cannot be studied too carefully, as having beauty, dignity, and meaning, and their employment is a

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suggestion of the fine continuity of the world's life. There are many conditions to be avoided in their use and some applications of them are much better than others. One does not, for instance, like to see them applied merely as decoration to the facade of a building, as has been done more than once by our best architects. This question may be open to discussion, but the persistence of the types of the order with the simple echinus, and that with the scroll beneath the rectangular abacus is, it would seem, assured and will be studied in the schools in centuries to come, certainly as long as stone and marble are used for building. In concrete and terra cotta or iron and steel we shall have, and are fast acquiring, other forms for the monumental expression of our constructive elements, and to know when and how to use each of these is to be the student's problem.

This article is concerned with the publishing of certain plates of the Greek Ionic and Roman Corinthian orders for elementary purposes, although it is felt that any attempt to confine to diagrams the life of an architectural form is usually filled with some danger to the beginner; it is also, more often than not, unjust to the form itself.

If it is borne in mind, however, that these plates are simply introductions to the systems of these orders, the diagrams may be of service to the future designer. Perhaps they will be more so if they are observed in connection with different applications of the same schemes during the centuries since their introduction to the world. Only a few of these are indicated in the sketches, and these are mostly of the Corinthian order, but they are enough to show that the proportions, the detail and the size depended on local conditions and only rarely on formulas, and then only in the most uninteresting periods of the history of the art of building.

The Ionic and Corinthian orders, while not closely resembling each other and neither being a development from the other, still have many features in common. They were both made up of elements foreign to Greece, the Ionic originating undoubtedly in Asia while the Corinthian bears witness to an Egyptian pro-

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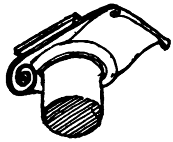
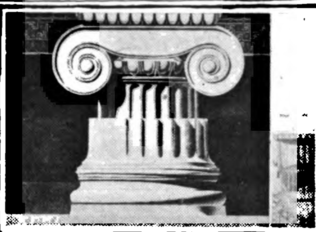
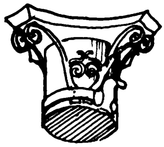


SKETCH OF SCHEME OF IONIC CAPITAL.



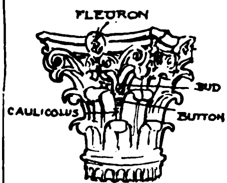
RENDERED DRAWING OF IONIC CAPITAL AND BASE - PROPYLÆA AT ATHENS.



SKETCH OF EARLY BRONZE DETAIL SUGGESTED BY M. CHOISY

CAPITAL FROM THE PALAZZO PICCOLOMINI AT PIENZA 1460

RENDERED DRAWING OF CORINTHIAN CAPITAL - TEMPLE OF MARS ULTOR ROME



ROMAN CAPITAL FROM THE BATHS OF AGRIPPA

CAPITAL FROM THE PALAZZO VECCHIO - FLORENCE. 1565

ELEVATION OF ACANTHUS LEAF

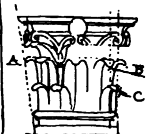
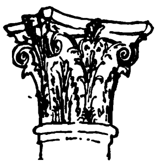


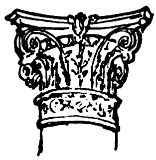
DIAGRAM SHOWING RELATIONS FOR DRAWING

ROMAN CAPITAL FROM THE FORUM OF TRAJAN.



CAPITAL FROM THE BADIA AT FIESOLE

GREEK CAPITAL FROM THE THOLOS AT EPIDAUROS



CAPITAL FROM THE PALAZZO MUNICIPALE AT BRESCIA 1498

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totype. These foreign ideas were adapted and refined by the Greeks and combined in their constructive schemes into forms of order and proportion. This was most characteristic of the Greek intellect, which rarely invented, but selected, developed and perfected to a wonderful degree. It is for us to apply the same spirit and find out whát elements in these classic forms are to be adapted and perpetuated and what are found lacking with respect to the principles of fitness and bèauty. It is now felt strongly that all art should bear the test of principled criticism, and we cannot for instance, accept and pass on as admirable, such unsatisfactory solutions of the designer's problems as the Greek Ionic corner column or the so called Asiatic Ionic base, the first of which defies the laws of balance and the latter those of unity.

The Ionic order as given in this diagram is of the form usually distinguished as the Asiatic Ionic, for it is found like this in the Greek colonies in Asia Minor. The probable wooden origin is evident in the slender proportions of the columns, and in those members of the cornice called the dentils as well as the membered architrave. It is easy to trace the development of this order archeologically from early Asiatic structures. The Ionic order as found in Athens and its vicinity was sturdier and perhaps not so graceful, although contrasted with the Greek Doric with which it was often used at the same time, these Athenian examples have grace and refined elegance where the Doric has force and logic.

The points to be observed in this diagram of the order are that the column being slender calls for a base and the Attic base (as shown in the General Section) is better and simpler than that shown in the larger diagram. The flutes are deep and are separated by a fillet. There is an echinus supporting the square abacus, but between the two and as if receiving and resisting the pressure from above, there is a cushion-like spring, the ends of which are rolled up like the undeveloped fern frond,— apparently by their resistance to the weight on the center of the mass. The fine feature about this capital is the life in this cushion and its ends or volutes and there is no reason why we

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should go on accepting poor substitutes for that living spring-like dip to the bottom of the cushion which is indicated here, but is lacking in many of the later Greek and Roman examples to say nothing of those of modern times.

The placing of the ornament in this order is considered by most of the best designers to be a most valuable object lesson in the principles of decorative design. This ornament was and is most appropriately carved instead of painted as in the Greek Doric.

Two modern applications of the Ionic order are shown. Its

THE KNICKERBOCKER TRUST COMPANY, NEW YORK CITY.
McKim, Mead & White, Architects.

use by Messrs. Shepley, Rutan and Coolidge at Conway is a purer one theoretically than that of Messrs. York and Sawyer at Washington — both in the form of the capital and the method of construction; but practically the larger scale of the latter demands the arch (the flat or keyed arch in this case) and the height of the entablature allows the voussoirs to be of the proper

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depth. Both of these modern examples are interesting as showing how the Ionic capitals were first and best used by the Greeks, between antae, or the side walls brought forward, the face of the volutes being parallel with the direction of the architrave. This direction of the main mass of the capital gives unity and meaning to the design and it was lost when the attempt was made by the Greeks to use this motive on a corner column. This problem was, to be sure, solved later by the Romans with the same general scheme of capital by making

ENTRANCE PORTICO, THE FIELD MEMORIAL LIBRARY, CONWAY MASS.
Shepley, Rutan and Coolidge, Architects.

volutes on all four corners, but the purity of the detail suffered.

The Corinthian order on the other hand, as we recognize it to-day, and as used for instance by the Knickerbocker Trust Co., is largely due to the Romans to whose characteristics as a people it appealed more strongly than the more subtle Ionic, and although perhaps the most beautiful Corinthian capital in exist-

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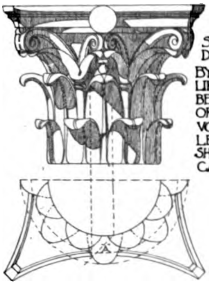
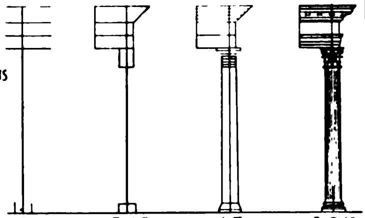


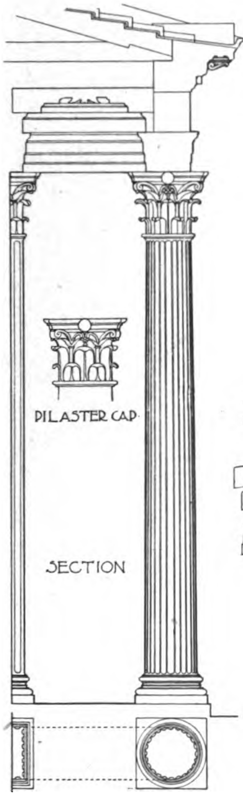
SHADE AND SHADOW ON CAPITAL.
BY MEANS OF SECTIONS LIKE "A" FIND ON THE BELL THE SHADOW OF THE ABACUS, VOLUTES AND LEAVES, AND THE SHADE ON WHOLE CAPITAL.

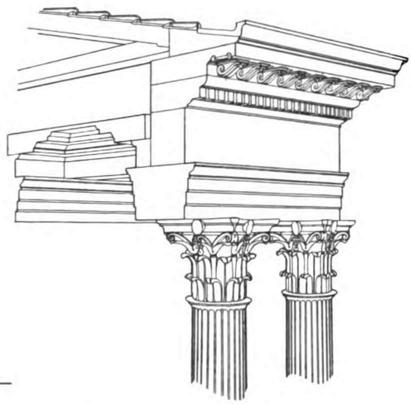


METHOD OF DRAWING THE ROMAN CORINTHIAN ORDER, GIVEN THE LOWER DIAMETER.

① LOCATE AXIS. ② LAY OFF HEIGHT OF ENTABLATURE. ③ LAY OFF HORIZONTAL DIVISIONS INCLUDING CAP AND BASE ④ FIND UPPER DIAMETER AND PROLONG OUTER FACE TO BASE OF CORNICE ⑤ FROM THIS POINT DRAW A LINE AT 45° TO GIVE MASS OF CORNICE ⑥ DRAW MASS OF SHAFT ⑦ DRAW HORIZONTAL PARTS OF CAP, AND FIND EXTREME CORNERS OF ABACUS BY LINES AT 45° FROM LOWER CORNERS OF CAP ⑧ DRAW HORIZONTAL PARTS AND PROFILE OF ENTABLATURE AND BASE ⑨ DRAW DETAILS OF ENTABLATURE AND CAP ⑩ DRAW FLUTES, USING A QUARTER PLAN AT BASE AND NECKING. DIVIDE THIS INTO 30 PARTS. 1 PART EQUALS ONE QUARTER OF A FLUTE.

THE ROMAN CORINTHIAN ORDER





PERSPECTIVE · SECTION · SHOWING · CONSTRUCTION ·

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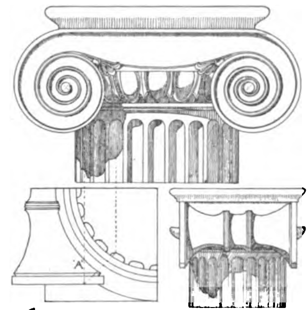
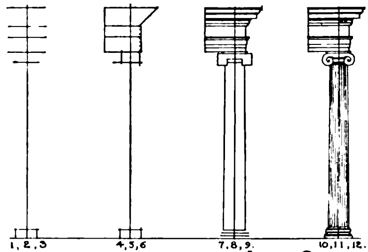


SHADE AND SHADOW ON CAPITAL

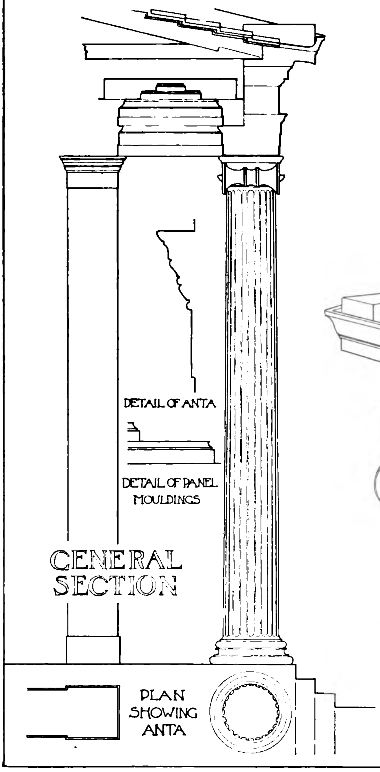
BY MEANS OF SECTIONS LIKE "A" FIND ON THE SHAFT THE SHADOW: ① OF THE VOLUTE, ② OF THE SHADE LINE OF THE BALUSTER SIDE, ③ SHADE ON ECHINUS AND SHADE AND SHADOW OF ASTRAGAL AND FLUTES.

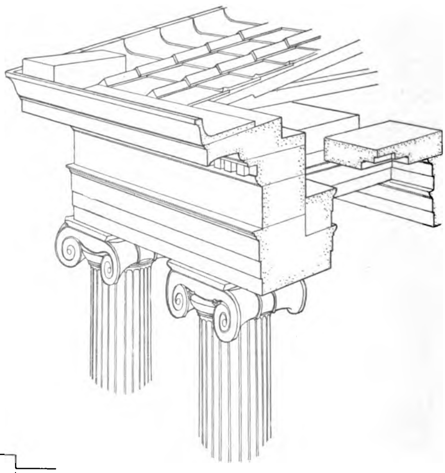


METHOD OF DRAWING THE GREEK IONIC ORDER ASIATIC FORM, WITH ATTIC BASE, GIVEN LOWER DIAMETER

① LOCATE AXIS. ② LAY OFF HEIGHT OF ENTABLATURE. ③ LAY OFF HORIZONTAL DIVISIONS INCLUDING CAP AND BASE. ④ LAY OFF FACE OF EPISTYLE AND FRIEZE ⑤ FIND UPPER DIAMETER, AND PROLONG OUTER FACE UNTIL IT STRIKES BASE OF CORNICE. ⑥ FROM THIS POINT DRAW A LINE AT 45° TO GIVE MASS OF CORNICE. ⑦ DRAW HORIZONTAL PARTS AND PROFILE OF CORNICE ⑧ DRAW MASS OF VOLUTES ⑨ DRAW PARTS OF EPISTYLE CAP AND BASE. ⑩ DRAW VOLUTES ⑪ DRAW DETAILS. ⑫ DRAW FLUTES, USING A QUARTER PLAN AT BASE AND NECKING. DIVIDE THIS INTO 30 PARTS: 1 PART = ¼ OF A FLUTE

THE ASIATIC IONIC ORDER





PERSPECTIVE SECTION
SHOWING CONSTRUCTION

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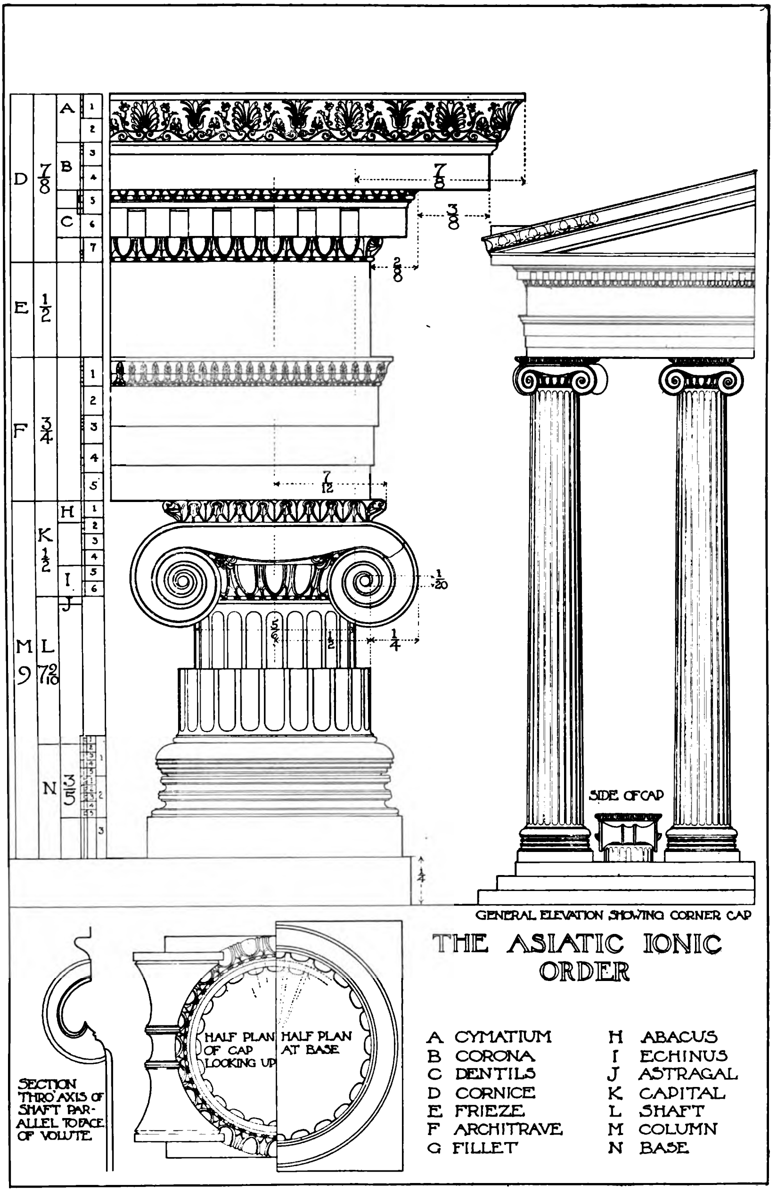

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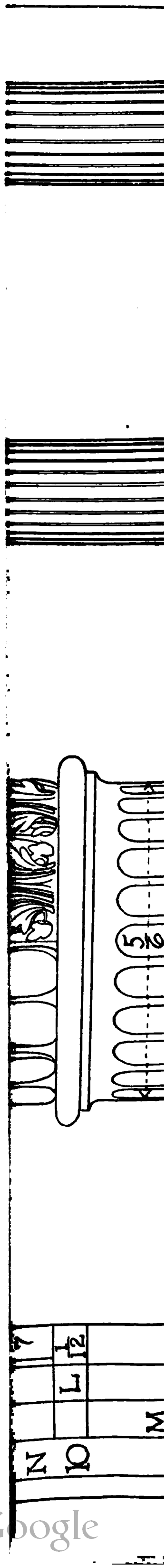

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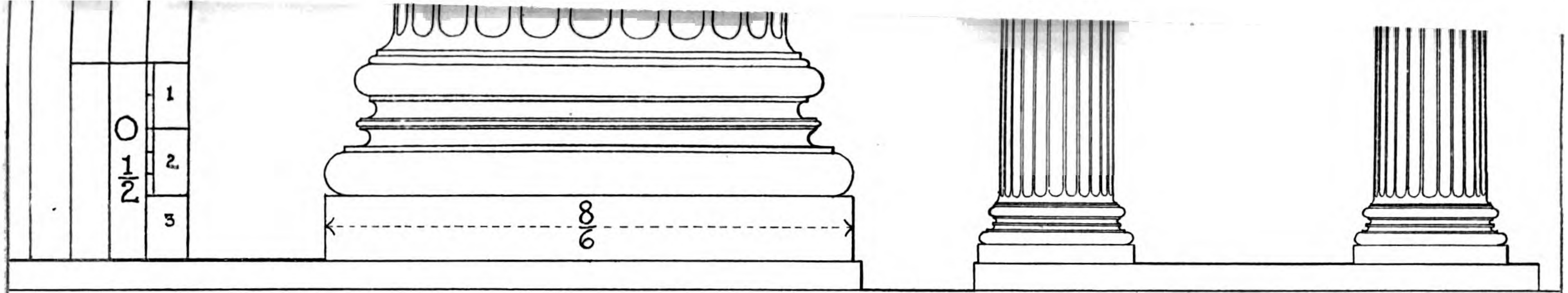
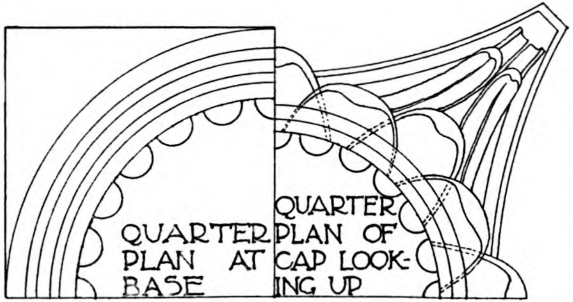
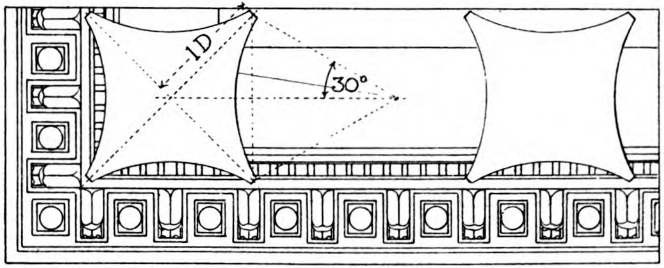


A ENTABLATURE
B CYMATIUM
C MODILLIONS
D DENTILS
E CORNICE
F FRIEZE
G ARCHITRAVE
H ABACUS
I LIP OF BELL
J VOLUTE
K CAPITAL



L ASTRAGAL
M SHAFT
N COLUMN
O BASE



PLAN OF SOFFIT OF CORNICE

ROMAN CORINTHIAN ORDER

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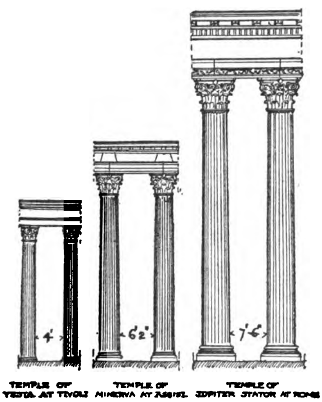
ence is Greek, that of the Tholos of Epidaurus, the developed type used at a large scale and appropriate to Roman civilization, and to ours in many of its aspects, was the work of the Romans of the Empire.

The Greeks treated this order usually as a slight and delicate decorative form as in the Choragic Monument of Lysicrates at Athens, or made the column a single ornamental feature as in the Temple of Apollo at Bassæ, but the Romans used it at a large scale in both exteriors and interiors, in temples, palaces and baths, sometimes most logically and again with more feeling for display than for architectural truth.

On the whole, however, its Roman career was most profitable to its development as a logical architectural element, for the mass of the volute was strengthened, giving more the appearance of support for the abacus and the arrangement of the two rows of leaves simplified into a scheme which the intelligence easily comprehends. Then the capital in detail was made to suggest a treatment of stone and marble rather than one which recalled its metal origin as the delicate, almost wiry carving of the Greeks often did. The earlier forms of the Roman Corin-



thian capital were sturdier than the later ones, both on account of the influence of the material which in the case of the Temple of Vesta at Tivoli was of a soft stone, and of the good

feeling for scale which led the designer to keep the masses simple. Contrast for instance the capital of the Temple of Vesta at Tivoli with that of the much larger order of the Temple of Jupiter Stator, which was of marble.

This question of scale is a most important one with regard to the use of the orders and the accompanying diagrams on page 113 prepared by M. Gaudet will show how such questions as that of the intercolumnation and the amount of detail depended upon constructive conditions and not upon formulas.

The Roman Corinthian order as given in the accompanying line diagram suffers from its restriction to definite numerical relations but, it serves to explain in plan and elevation the system. A good description taken from a current text book is as follows:

*"The Corinthian capital is in form similar to a cylindrical vase covered by an abacus with hollowed sides and with corners cut at an angle of forty-five degrees, in plan with the sides of the square containing the abacus. Against this vase or 'bell' are placed two rows of leaves whose heads are curved. The first row which is applied directly above the astragal of the shaft, is composed of eight leaves; these are called the small leaves. From the intervals between these small leaves arise the stems of the second row of leaves which are larger. Between these large leaves and just over the centers of the small ones, eight stems arise, from which develop eight other leaves, which divided into two parts, recurve above the large leaves at the corners of the abacus and at the center of each of its faces.

"These leaves, which are very much distorted, are called caulicoli. From these caulicoli arise sixteen volutes of which eight large ones unroll in pairs, back to back, under the corners of the abacus, and eight small ones, also in pairs, extend towards the centers of the four sides of the abacus. Above the small volutes and against the mouldings of the abacus is a rosette. The small leaf is placed on a vertical axis against the base in such a manner that the base rests on the astragal and its face corresponds to the face of the shaft."

* Bourne and Brown "The Roman Orders."

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The Roman Corinthian Entablature differs from the Ionic chiefly in the details of the cornice. In addition to the dentils in the latter there are the larger consoles or supporting brackets under the corona. These vary in the different examples of the orders from the plain rectangular masses, to the modeled forms shown in the diagram. The points which seem essential in the design of this order are that the fine continuity of the line of the shaft through the profile of the capital shall be kept, and that the mass of the volutes shall always be heavy enough.

In drawing the form it is, as one can see, very essential to have the plan, for the correct positions of the details of the leaves, as well as a proper conception of the system of the acanthus leaf, with the relative importance of the mass first followed by the spine, the eyes, the pipes, the lobes and lastly the leaves. Then it is to be remembered that in drawing the capital at a small scale the vertical elements are to be emphasized or the cap loses its character of support.

The sketch diagram indicates one or two convenient relations which help one to draw the elevation of the capital at a small scale. The line drawn tangent to the astragal from the end of the echinus is tangent also to the upper leaf at A. The lower diameter projected up gives the point of the lower leaf C and the upper diameter has the same relation to the leaf B.

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TRAIN RESISTANCE IN RELATION TO THE TRACK.

By P. H. Dudley, C. E., Ph. D.

The construction of an efficient track to reduce the resistance of the passenger, mail, express and freight trains, is one of the important objects in building a railroad. The theory of the location of a line in reference to gradients and curvature, as elements of train resistance, has received extensive discussion. The theory of causing the centers of gravity of all the wheels and of the bodies of the locomotives and cars to move over the track with the least possible undulations, to reduce train resistance, has not incited academic discussion, though practically it has been given great attention. It is the problem on which I have been engaged the past three decades, and by the introduction of stiffer rails have reduced the undulations in the track, from 6 to 8 ft. per mile, to 2 ft., on 100 lb. rails, as measured by my Track Indicator.

The railroad companies in the United States for 1903 expended $126,000,000 for labor to surface and keep the tracks in order, and reduce the train resistance, and this is likely to increase per year.

Tests have been made upon the resistance of single cars and short trains, at slow speeds, from the inception of the railroads. The results were of technic value for comparison with those of other systems of transportation which they were to replace, and excel in capacity and speed. Those tests for present service are of more historic interest than practical application, as the condition of the track, on the 15 ft. or shorter rails, was inferior to the present smoother tracks, and the resistance two and three times greater per ton than upon the larger cars and trains now in service.

The resistance of the short loaded cars in England in 1830 was found to be 10 lbs. per ton of 2240 lbs. for speeds of five to ten miles per hour. The same cars empty ranged from 11

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to 12 lbs. per ton. The wheels were 3 ft. in diameter, and the journals 1.75 inches in diameter by 3.5 inches in length.

Improvements in the construction of the cars and the substitution of brass for the journal bearings, reduced the resistance, to a slight extent.

Chev. F. M. G. De Pambour, in 1834, when making tests upon the English locomotives and trains of the Liverpool & Manchester Railroad, at five to ten miles per hour, found that the resistance was about 9 pounds per ton, in trains of five or six loaded coal wagons, while for single cars it was from 11 to 12 lbs. Each car loaded weighed five to six tons. His book on "Locomotive Engines upon Railways" is and will remain a classic upon the Theory of the Locomotive.

Mr. Johnathan Knight, Chief Engineer of the Baltimore & Ohio Railroad, made some experiments upon the resistance of single four-wheel cars, and found that by coning the wheel treads, he could reduce their resistance on the curves he was obliged to adopt for the line.

The flexible four-wheel truck was invented, and one placed under each end to support the car body as in present service. This was an adaptation of the rolling stock to the track of far reaching importance to American railroads, which were being built to develop the ample resources of an extensive country.

The tracks at the inception of the railroads in England were constructed upon the theory of an inelastic roadbed, with rigid foundations as for buildings with static loads.

Stone blocks with foundations were provided, upon which the rails or stringers rested, to carry dynamic rolling loads. It was expected that these would prove permanent constructions of great durability, instead of failing after a short service. The stone blocks and foundations were copied at first in this country, by the Baltimore & Ohio, the Mohawk & Hudson, the Boston & Lowell and many other railroads, but were abandoned for cross-ties on ballast. The four-wheel engines, either imported or constructed in this country, at even ten and fifteen miles per hour, rode with decided undulations over the tracks.

The Mohawk & Hudson Railroad, from Albany to Schnec-

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tady, was chartered in 1826. Construction commenced in 1830, and the road opened in 1831. There was one inclined plane at Albany, and one at Schenectady, the locomotives traversing only the nearly level plateau between the heads of the inclines. It had a strap iron rail 2.5 inches by $\frac{9}{16}$ of an inch thick, spiked centrally upon pine stringers 6 by 6 inches, resting upon stone blocks of 3 ft. centers, which were set upon broken stone foundations in the road bed.

Mr. John Bloomfield Jervis, the Chief Engineer, had the "De Witt Clinton" constructed by the West Point Foundry, for one of his locomotives, and one constructed by Robert Stephenson & Company, Newcastle-on-Tyne, England, and named the "John Bull." The "De Witt Clinton" weighed 6,758.5 pounds, the "John Bull" 12,742 pounds, of which 8,745 pounds was upon the single pair of driving wheels. Both had four wheels and a wheel base of 4.5 feet, though in the case of the "De Witt Clinton" both pairs were driving wheels.

The strap iron rail formed the bearing or sustaining surface for the wheel contacts, and guide for the passing locomotives and cars. The stringer supplied the strength as a girder. The weight of the "John Bull" was too heavy for this superstructure, and was not distributed by a wheel base sufficient in length to ride steadily over the track, and was seldom used, as first received.

Mr. Jervis prepared designs for a new engine with his "leading and guiding four-wheel truck," which was constructed at West Point Foundry in 1832, and called the "Experiment." This demonstrated the value of the principle of distributed loads of the engine.

Mr. Jervis sent similar designs to Robert Stephenson & Company, Newcastle-on-Tyne, and a locomotive was constructed, called the "Davy Crocket," received and ran on the Saratoga & Schenectady Railroad in 1833.

Mr. Jervis was also Chief Engineer of this railroad. He constructed three miles only with stone blocks, substituting cross-ties and ballast, adapting the flexible superstructure to

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the elastic subgrade. A four-wheel truck was substituted for the front pair of wheels in the "John Bull," which then rendered service on the Mohawk & Hudson for many years.

Mathias W. Baldwin, the founder of the Baldwin Locomotive Works, visited the Mohawk & Hudson Railroad, and adopted and used the Jervis truck for the construction of his second locomotive, the "E. L. Miller," in 1834.

Henry R. Campbell's American or eight-wheel engine followed in 1836, which now had sufficient lateral and vertical flexibility, with the necessary weight for adhesion, to run over the mountain divides superseding inclined planes.

On the Mohawk & Hudson Railroad was the inception and installation of the American theory and practice of subdividing the total load of the engine, and utilizing a portion of the weight by a forward "leading and guiding truck" to take up the looseness of the track, stiffen and strengthen the portion of the rail occupied by the heavier loads of the driving wheels. The general depression of the rail started by the forward truck wheels is continued under the driving wheels in part by the drawbar-pull, to the rear portion of the rail held down by the following wheels of the tender. With this principle of distributing the loads of the locomotive, the constraining of the stiff line section in the general depression is so efficient that the greater weights carried upon the driving wheels do not produce a proportional increase of stress, even with the expenditure of their tractive effort to the load carried upon the truck. The rail instead of forming a deep depression under the driving wheels, is retained in a more level and uniform surface in the general depression than would be the case without the assistance of the weight upon the forward truck.

Utilizing the favorable mechanical principles between the running engines and stiff rails, by causing a part of the load to stiffen and strengthen the permanent way, is unique in Mechanics, and has rendered possible the unexpected development of the railroads in the past two decades. Extending the same principle of subdivision of the load to larger types of locomotives having more than two pairs of driving wheels, the effect

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of the distribution of the increased load of the locomotives upon the stiff rails has been rendered exceedingly advantageous.

The load of the locomotive produces on the track a distinct general depression, with specific deflections under its wheels. This is illustrated in Figure 1, by a locomotive on a section of track.

The trackman's surface of the rail, represented by the broken line, is in its normal position only when unloaded. It is depressed by the moving loads of the locomotive and cars to its lower loaded surface in the general depression for the necessary

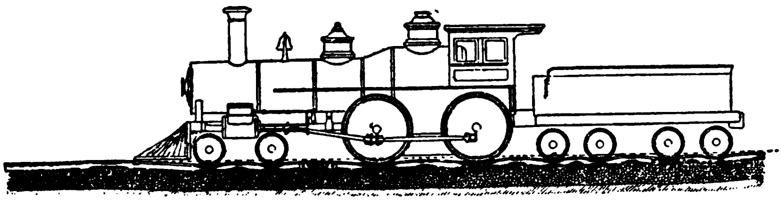

Fig. 1. The vertical scale of the "general depression" is enlarged 24 times over that for the length of the locomotive.
Fig. 1 illustrates the general depression of the rails, cross-ties, ballast and subgrade from the "trackman's surface" under moving locomotives.
The rail section from its mechanical properties as an engineering structure in distributing the wheel effects, resolves them into positive bending moments under the wheels and the constraining negative bending moments in the wheel spacing.

conjoint support of the subgrade to carry the loads which are transmitted and distributed only through the wheel contacts and produce specific unit fiber strains under them in the rails.

Examination of the tracks in England, Belgium, France or America, discloses that the superstructure of the permanent way is restricted in depth and weight, and from its flexibility and elasticity when unloaded, is a floating mechanism held in surface or not by the ballast resting on the compressible subgrade.

The rails and cross-ties are depressed by the wheel loads in the ballast from one-eighth to three-eighths of an inch under the present heavy locomotives and cars. The compression of the ballast and subgrade forms one-fifth to one-third

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of the total amount of the temporary subsidence of the rail. The subgrade is affected to a depth of twelve to twenty feet, according to its material, construction and stability. There is a characteristic general depression of the rails, cross-ties, ballast and subgrade produced by each type of locomotive or car to carry and distribute the loads with specific deflections in the rails under the wheel contacts.

The reduction in train resistance from the inception of the American railroads to date is due to two important factors:

First. The improvement of the track.

Second. The adaptation of the equipment to the permanent way.

Robert L. Stevens, President and Chief Engineer of the Camden and Amboy Transportation Co., designed the prototype of the present Tee rail sections, in 1830, of about 40 lbs. per yard, height 3.5 inches, base of equal width, and the head about $2\frac{1}{8}$ inches wide. It was laid in the track in 1832, in 16 ft. lengths, and spiked directly to the cross-ties. Upon the light short iron rails, the resistance did not reduce much under 8 lbs. per ton, for freight trains, and was more for passenger trains. The weight of the section was increased per yard, though made more pear shaped for the head and web than in the Stevens section. The engines were enlarged, and the sections augmented in weight and height, which caused the iron rails to crush and exfoliate in the bearing surface. This was attributed to the quality of the iron, while the real cause, passed unnoticed, of the greater duty imposed upon the bearing surface of the rails by the larger bending moments, to make stiffer and smoother tracks. Many of the railroad companies returned to the use of more limber iron rail sections, which increased the train resistance. This was an embargo upon the development of the locomotives, cars and trains, while the cost of maintenance was excessive. Steel capped rails were tried, but soon failed.

Bessemer's invention of the pneumatic process for making steel furnished a product which in the early rails of 1865 to 1875 rendered excellent service in the bearing surface. One

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steel rail would outlast ten to fifteen iron rails, and enabled the railroads to establish higher standards of maintenance of way, which reduced the cost of operating, but only to a slight extent the train resistance.

The stiffness of the rails was even less than some of the iron rail sections, and the locomotives were not enlarged.

Experiments upon train resistance were made in England, from which D. K. Clark advanced a formula having a factor which increased as the square of the speed. Reduced to American tons of 2000 lbs. it is $R = 7.2 + 0.053\ V^2$. R being the resistance in pounds per ton (2000 lbs.) and V the speed in miles per hour. This was accepted by Civil Engineers of the United States, from about 1865 to 1875, as approximately correct.

As chief engineer of the Valley Railway Company of Ohio, 1872 to 1875, I concluded from observations that this was an over estimate for American trains and track. I wished to run freight trains of 1200 tons gross weight, and the formula indicated it would be beyond the capacity of the existing locomotives. In 1873–4 I constructed my dynagraph, and found that while the formula was high for freight trains, it was excessive for passenger trains of 200 to 250 tons.

Mr. C. O. Mailloux in his article on Train Resistance in the April, 1905, number of the JOURNAL, has stated several of the important features of my investigations, so that it will be necessary only for me to refer to the prominent results.

Tests which I made on Train Resistance on the Lake Shore & Michigan Southern Railway, in the winter of 1875–6, indicated that less fuel was consumed at speeds of 18 to 20 miles per hour, on stock trains, than the slower running trains of 12 to 16 miles per hour. For ordinary freight trains 16 miles per hour was the maximum speed allowed at that time, but was soon increased. The train resistance ranged from 7 to 8 lbs. per ton.

Tests upon different roads indicated that upon new rail, well surfaced, the train resistance was less than upon the older rails with low joints, other conditions being similar. This was

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observed in several tests upon the Boston & Albany Railroad in 1876–7, and was one of the most important practical results obtained, for with better track the resistance was reduced for every wheel which passed over it, by checking large generated destructive dynamic forces. I made a test in 1878 upon the New York Central & Hudson River Railroad, from Buffalo to Albany, of a passenger train of nine cars of 300 tons weight, in which the average resistance at 50 to 52 miles an hour, was from 11.5 to 12 lbs. per ton, about two thirds of that estimated by the Clark formula.

In descending the Batavia grade the speed attained was 60 miles per hour, but on the levels the maximum was from 51 to 52, the full steaming capacity of the boiler of the engine.

These tests showed conclusively that to increase the speed of the train it would be necessary to quicken the steam generating capacity of the boiler, and make the track smoother. The rails were laid with opposite joints. Such facts having been ascertained, the next investigation was the condition of the track, which was undertaken by the complete apparatus I designed for my Track Indicator. The diagrams of the undulations of the rails, under the load of 19 tons on the special six-wheel truck, indicated that the rails in all tracks had common forms of permanent set, of such magnitude labor alone could not correct them.

The light and limber rails had only small constraining negative moments in the wheel spacing, the major portion of each wheel effect being delivered to the cross-ties as they were passed. The generated dynamic shocks were so great they indicated on the dynamometrical curve at each joint. Every wheel beside overcoming the "fictitious grade" was delivering dynamic shocks of more or less magnitude, to the permanent way.

Stiffer rails were required to distribute more of the wheel effects in the wheel spacing and relieve each cross-tie of as great percentage of each wheel load as was permitted by the limber rails.

I designed in 1883 the pioneer five inch 80 lb. steel rail for the

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New York Central & Hudson River Railroad, which was rolled and laid in the Harlem Line in July, 1884. It replaced the 4.5 inch 65 lb. rail and with only 15 lbs. or 23 per cent. more metal was 60 per cent. stiffer, and 40 per cent. stronger with a broader head for greater combined stability between the speeding locomotives, cars and the permanent way, than the 65 lb. rail.

The service tests of the rail were awaited with interest by railroad officials, the results in smoothness and stability of track exceeding their expectations.

The heaviest axle load under engines was 31,750 lbs. or 63,500 lbs. for the two pairs of driving wheels, and was limited to 27 locomotives built in 1882 for the New York Central & Hudson River Railroad. The preceding class of large locomotives had driving wheel axle loads of 26,500 lbs., while to-day, 1905, several locomotives are in service with 55,000 lbs. per axle.

Mr. William Buchanan, superintendent of motive power, New York Central & Hudson River Railroad, in 1889 designed his famous locomotive, No. 870, with 80,000 lbs. upon the two pairs of driving wheels, 40,000 lbs. upon the forward truck, and 80,000 lbs. upon the tender, when filled with coal and water,— the first 100-ton locomotive.

The stiff 5-inch 80 lb. rails made so smooth and stable a track and reduced the train resistance to such an extent, that on Nov. 30th, 1891, the "Empire State Express" was installed,— the most famous long distance train, the educator of the world in practical rapid speeds. The distance from New York to Buffalo, 440 miles, was run, including three stops and two changes of locomotives, and 28 "slow downs," in 510 minutes, or eight and one-half hours. This schedule was continued until the autumn of 1895, when the time was shortened fifteen minutes, and has been since maintained.

The weight of the locomotive and four coaches was originally 270 tons, which has since been increased.

The train resistance, as indicated by the Clark formula, as was well known before attempting to run the train, proved to be much in excess of the facts. The foreign technical journals did not accept the results for some years.

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Railroad officials have been quick to see the decided advantages of the stiffer and heavier sections, from the pioneer 5 inch 80 lb. rails, and replaced their 4.5 inch by 5 inch sections of 80 lbs. or more weight per yard. The enlargement of the locomotives made great progress on the stiffer rails, which had not been possible on the light steel sections, owing to their weakness as girders.

The replies of the railroad companies to the inquiries for the International Railway Congress, Seventh Session, Washington, D. C., May, 1905, show that in the past fifteen years on the stiffer rails the locomotives have doubled in axle and total loads. The possibility of doubling the weight of the passenger, express and mail trains, and run them upon schedules but little slower than the high speed trains, has been equally and perhaps more important to the railroads and community.

The reduction of the undulations in the track, as shown by my Track Indicator, from 6 to 8 ft. per mile, in 1881, on the light and limber rails, to 2 and 3 ft. per mile in 1900 on the stiffer and stronger rails, on the same road bed, measured by the practical results attained, has been doubling the capacity for axle loads and volume of traffic.

Freight trains of 3000 and 4000 tons, on lines of moderate gradients, are possible only on tracks of great combined stability and smoothness.

Railroad officials have taken advantage of such possibilities, as the only way earnings could be secured, from an average freight rate of less than one cent per ton mile.

The results attained by the introduction of the stiffer rails in the same road bed show that it has been the best, quickest and most economic way that the railroad companies could increase the stability and capacity of their roads.

I was able to estimate and state the limited undulations in the track of the stiff rails which would be shown by my Track Indicator, before the pioneer 5 inch 80 lb. rails were rolled. They denoted higher standards than had been previously attained, and to officials seemed improbable. The computed results for the Boston & Albany Railroad with stiff rails and

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good material, were that the condition of track would show between the 15th and 16th lines on the condensed diagram. These were stated in 1883.

Mr. William Bliss, president of the company — a Harvard graduate — commenced to lay the $5\frac{1}{32}$ inch 95 lb. rail in 1891, and completed the entire track in 1897. The average sum of the undulations for the track inspection of that year was $15\frac{42}{100}$ lines on the condensed diagrams. I had made all of the rails at the mills of high carbon steel, and lengthened the anvil blocks on the straightening presses, and the rails were finished smooth. It was known what was required, and achieved.

The increased smoothness of track, for maintenance and operations, saved the cost of relaying with the 95 lb. rail, in less than seven years.

Fig. 2 shows a diagram of the surface undulations of the

FIG. 2. Diagram of Main Line tracks, 1881. Undulations eight feet per mile. Vertical scale actual. Horizontal scale one inch to fifty feet, in the original diagrams. Figs. 2 and 3 reduced to two thirds size.

track in 1881 of 8 ft. per mile, where each joint gave a shock to the passing wheels.

Fig. 3 shows a diagram of 1895, of limited undulations, the

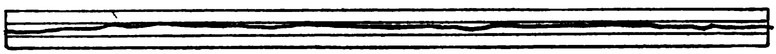

FIG. 3. Diagram over same track in 1900, laid with six-inch 100 lb. rails Undulations under same wheel loads one foot nine inches per mile. So smooth, the three tee joints do not produce shocks to the passing wheels.

joints so smooth as not to be indicated.

The opportunity to test the value of smoothness of the track in running passenger trains of over 700 tons is so infrequent, that the following is of interest as an achievement.

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The heaviest passenger train on record which has been run at a speed exceeding 60 miles per hour was the "Southwestern Limited," on the New York Central & Hudson River Railroad, Aug. 19th, 1899. The travel was heavy, and several extra cars were added, forming a longer and heavier train for that day than usual. There were 16 cars and coaches, making the total length of the train from the tip of the pilot to the rear buffer 1212 feet, nearly one quarter of a mile. The total weight was 1,840,000 lbs. or 920 tons. The schedule time of the train, from New York to Albany, to make two stops and five slow-downs, was 3 hours and 15 minutes, to run 143 miles. The train was made up on two different tracks at the Grand Central Station, and was 5 minutes late in leaving. The stop at Harlem required one for the front of the train, then a second for the rear. The actual run was made, including the stops and slow-downs, in 3 hours and 12 minutes, and a speed of over 60 miles per hour was attained at several places.

The engine was a 10-wheel type, 40,000 lbs. on the truck, 128,900 lbs. on the drivers, which were 70 inches in diameter; tender 102,000 lbs.; total, 270,900 lbs. Cylinders 20 by 28 inches. Steam pressure 200 lbs. The stremmatograph tests of the unit fiber strains in the rails, under the passing locomotive, show per lb. of static load about 15 per cent. less than those of the 8 wheel type, when doing proportional work, a fact of importance for heavy trains.

On the lower portion of the road 100 lb. rails were in service, to Dutchess Junction, 57 miles, and from there to Albany new $5\frac{1}{8}$ inch 80 lb. rails had been recently laid. These were finished smooth at the mills, and had been in the track a sufficient time to be in excellent surface.

The train resistance proved to be less than the usual estimates, in part due to making the trackmen's surface and that of the steel as smooth as possible. The rails were laid with alternate 3 tie supported joints. In passing over the track with the track indicator later in the season (October), there was scarcely an indication of the joints shown upon the diagram, from New York to Albany.

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The stiffer and better finished rails, both in surface and alignment, have contributed to a reduction of the shocks and oscillations of the cars which obtained on the light and limber rails, thus effecting a saving in train resistance, cost of operating, and adding to the comfort of travel.

Mr. Mailloux, in his able analysis of Train Resistance —April, 1905, number of the JOURNAL, page 47 — states that —

"The average effective fictitious grade, due to track hysteresis, in case of a car or train, is affected by and depends upon so many things, that the study of the yielding effects produced at a single wheel is far from sufficient to give an adequate idea of the phenomenon as a whole or to furnish a clue to the amount of total resultant effect on the train resistance in each case."

This coincides with the important principle of the total load of the locomotive or car distributed by several wheels, each constraining the wheels either side, in opposition to the opinion of independent single wheel loads.

This forms the distinctive feature of American practice, which I have long considered as the basal principle. The results of service secured in the transition from the light and limber sections to the stiff and heavy rails prove, there are principles underlying the present practice, which need investigation for elucidation to explain what has been achieved.

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Editorial.

The development of the Puyallup River water power described in this issue is characteristic of the present western practice. Similar installations are frequently used in the

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reclamation of arid lands where, in preference to carrying water in flumes, water power is developed and the power is transmitted electrically for pumping from wells.

During its last annual meeting, the American Electro-Chemical Society held one of its sessions in Pierce Hall and afterwards was received by President Eliot and tendered a luncheon in the Union.

Those of our readers who are interested in the Panama canal, will be glad to know that Gen. Henry L. Abbot has just published a book on the "Problems of the Panama Canal."

Graduate Notes.

J. P. H. Perry, '03, has recently been connected with the completion of a large concrete bridge on the Chicago, Burlington & Quincy R. R., at Big Rock Creek, near East Plano, Ill. The bridge was built in freezing weather and as a means of ensuring prompt setting of the cement the whole structure was heated by steam. An account of the bridge appears in the Railway and Engineering Review for December 12, 1903.

K. E. Adams, '03, is now an assistant in the Engineering laboratory. He is also working with Mr. E. D. Leavitt, M. E., in Cambridge.

S. Cunningham, '01, has announced his engagement to be married.

J. W. Coolidge, '01, has left the American Locomotive Company in Schenectady and is now in the office of the Superintendent of Machinery of the Louisville & Nashville R. R. Co. Address, 722 West Chestnut St., Louisville, Ky.

G. C. Kimball, '00, is assistant chief engineer of the American Sheet & Tin Plate Co. Frick Building, Pittsburg, Pa.

J. A. Moyer, '99, has lately published a second edition of his Descriptive Geometry, revised very thoroughly and more than doubled in size. The left hand pages are reserved for the text, while on the right appear some 77 illustrations and blank pages for notes. In the Engineering News for

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May 18, 1905, p. 535, Prof. Henry S. Jacoby of Cornell speaks very highly of this book. He especially commends the logical order of the problems and the numerous graded exercises which are admirably suited for use in the classroom. As a whole, he considers the book "well adapted to the needs of engineering colleges, and in a number of important features the most satisfactory one now available."

Architectural Notes.

For the recent examination for the Julia Amory Appleton Fellowship in Architecture four candidates presented themselves, of whom, however, one withdrew before the examination, leaving A. E. Hoyle, '04 A, R. W. Varney, '04 A, and H. E. Warren, '04 A. These three candidates were first required to pass an examination on a special period of architectural history. The subject for the examination in design was an Atheneum "in an important city which is engaged in extensive civic improvements." "The Atheneum is a corporation whose building is to contain a library, an art gallery and a lecture room." The competitive designs were first submitted in the form of preliminary eight hour sketches. The candidates were then given three weeks for the preparation of the final drawings.

These were examined by a committee appointed by the Department of Architecture with the approval of the President, consisting of Mr. R. S. Peabody, Mr. E. M. Wheelwright and Mr. R. C. Sturgis, acting with the instructors in the Department. After a careful examination, the committee unanimously decided to recommend Mr. H. E. Warren for the fellowship. Mr. Warren who lives in West Somerville is twenty-three years old and came to the Department of Architecture from the Rindge Manual Training School. He graduated from the Department of Architecture in 1904 with a "magna cum." He has spent the last year in post graduate study in Architecture, holding one of the Austin Resident Scholarships. Mr. Warren will spend two years of study and travel abroad and will work during a large part of his time at the American Academy in

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Rome. The holder of a Fellowship in Architecture is required to submit monthly reports of his progress and to send at the end of each half year a measured drawing of some monument of architecture, which must be approved by the Department. He is also required to make during his stay in Europe, a special study of a single building or group of buildings, and on his return must present a written essay, illustrated by drawings, embodying the results of this study. Mr. Warren expects to go to Rome in the early fall.

J. E. Somes, Jr., '01 A, and E. M. Parsons, '03 S., have recently established themselves in practice in the Paddock Building, 101 Tremont St., under the firm name of Somes and Parsons.

W. S. Parker, '99 A, is in the office of Messrs. Sturgis and Barton in Boston.

E. B. Van Winkle, Jr., '04 A, is in the office of Messrs. Trowbridge and Livingston in New York City.

The firm of Whitfield and King of New York, of which H. D. Whitfield, '98 A, is senior partner, was employed for the design for the new library at Tufts College in Medford, near Cambridge.

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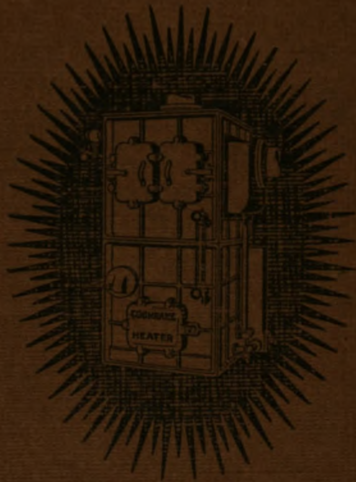

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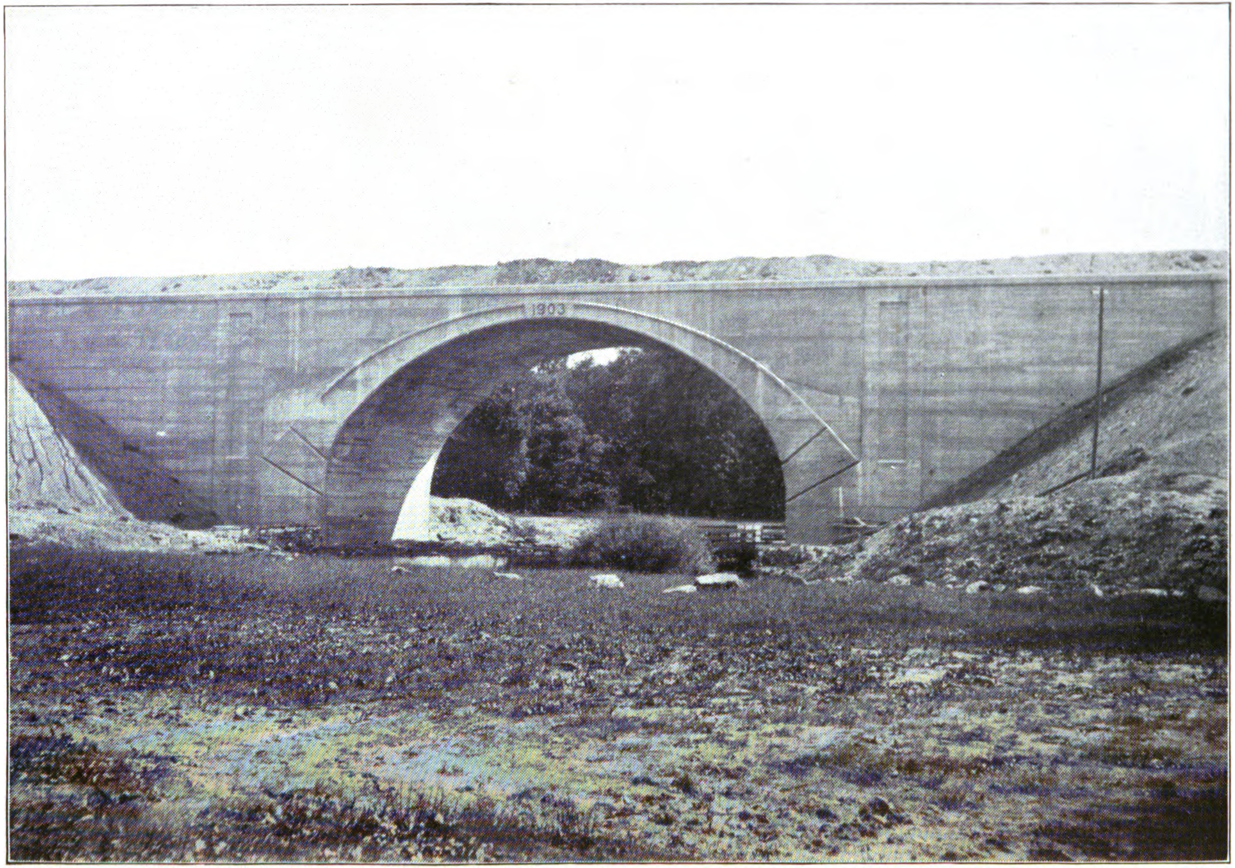

FIG. 1.—CONCRETE ARCH,
CHICAGO, BURLINGTON & QUINCY R. R., PLANO, ILLINOIS (page 140).

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VOL. IV NOVEMBER, 1905 NO. 3

THE HISTORY, MANUFACTURE, AND PROPERTIES OF HARD DRAWN COPPER WIRE.

BY THOMAS B. DOOLITTLE.

THAT the adaptation of a well known principle to meet conditions sometimes leads to important results is well illustrated in the story of the raising of the Obelisk in the Piazza di San Pietro, Rome. The populace were commanded under penalty of death to keep silent. At a critical moment, when the Obelisk had nearly reached a perpendicular position, the ropes proved too long. A sailor cried out "Aqua alle funi" (wet the ropes). This was done, and the shrinking of the ropes set the Obelisk squarely on its base. It will be remembered that the sailor (Bresca) received a reward instead of the penalty.

Hard drawn copper wire was the result of an adaptation rather than a discovery, although many of its valuable properties were not appreciated until after it had been in service several years.

It is the common knowledge of all who are familiar with the manipulation of copper that the process of drawing it into wire serves to harden the surface. Thus it will be seen that the experiments which resulted in the so called hard drawn copper wire were based upon a well known principle, although the application of this principle had never been made use of for the final product. The writer was familiar with this phenomenon at the time he entered the field of electricity; therefore, when it was disclosed to him that copper was not only one of the best conductors of electricity but was the cheapest in conduc-

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tivity, or per mile ohm, it was only left for him to determine whether or not this hardening process could be made available, in order that copper wire should be comparable to iron in its ability to stand the strain of its own weight when strung on poles, and, in addition thereto, the weight of sleet or snow and wind pressure. There was no mathematical road to determine this factor; therefore, it was simply a case of "cut and try."

First, the size of the finished product was fixed upon (#12 B. & S. gauge); then it became a matter of experiment to determine the size of the annealed copper rod which, when drawn to this predetermined size, should possess the proper tensile strength and the required torsional property. It was also necessary to determine the number of "holes" or reductions that should intervene in the process of drawing in order that the structure or fibre of the metal should not be injured during the process. Too much force would result in granulating the metal and thereby impairing its tensile strength. The experiments proved all that could be anticipated, and a sufficient amount of hard drawn copper wire was manufactured to equip the lines necessary to connect all of the mills, offices, and residences of officers of The Ansonia Brass and Copper Company, in whose wire mill these experiments were made. A telephone switchboard was set up in the brass mill of that company, and an operator answered calls and made connections. This work was begun in November, 1877.

Although the product is known in the trade as hard drawn copper wire, and properly so known — as the name indicates its property of hardness and the method of manufacture, — the name has no antonym or contra-term because soft drawn copper is a misnomer; the very process of drawing eliminates the quality of softness and makes it hard.

Prior to its introduction for aerial electrical conductors, there was very little, if any, call for the hard product. Copper wire was usually annealed after drawing, and sold in that form. Copper alloyed with other metals was, and is now, used in the manufacture of hard or "spring wire."

Scepticism on the part of electricians and generally in scien-

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tific circles, as to the practical value of this adaptation, prevented its being adopted to any extent, except the few circuits that the writer introduced into the Bridgeport, Connecticut, telephone exchange, until seven years afterward.

In 1884 the writer was commissioned to construct an experimental metallic circuit of copper between New York and Boston. The wire for this circuit was drawn under his personal supervision in the wire mill of the Bridgeport Brass Company. The total cost of this experiment was, in round numbers $70,000. After the experiment was concluded, the wires were turned over to the intervening telephone companies for local use, and immediate steps were taken to build the New York and Philadelphia long distance telephone line. The miles of hard drawn copper wire now in use for all electrical purposes are counted by millions.

The first recorded employment of copper as a line conductor was its use by Prof. Morse in his experimental telegraph line between Washington and Baltimore. The ordinary market wire was used but, for the reason that it would not sustain its own weight, it was abandoned and iron wire was substituted. The next of record was strung by the Western Union Telegraph Company, in New Jersey. In this case, also, the ordinary copper wire was used, but an attempt was made to increase its tensile strength by twisting a pair of wires into the form of a rope. This did not prove a success and was abandoned for the same reason as the other. In the early seventies many experiments were tried in attempts to make available for aerial line conductors the superior conductivity of copper. In each case a steel wire was employed for tensile strength. In one case a copper ribbon was wound spirally around the steel wire. On exposure to the elements a chemical action was set up that quickly destroyed the steel core. This ribbon was afterward tinned, but with unsatisfactory result. In another experiment the copper ribbon was folded longitudinally. The last and most successful in this line of experiment was the process of electroplating the steel wire with copper. This was put in service by the American Rapid Telegraph Company, but in a few years it

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also proved unsatisfactory and was abandoned. Therefore it will be seen that the first successful employment of copper wire for electric line conductors was on the telephone lines of The Ansonia Brass and Copper Company in 1877, and the Bridgeport, Conn., telephone exchange in 1878. The next was on the line between New York and Boston in 1884. The latter experiment was an immediate success, and hard drawn copper wire was, within a few months, adopted throughout all civilized countries.

In recent years great improvements have been made in the process of manufacture, which cover all operations from the ingot to the finished product. At the time recorded above it was the practice to roll a billet of copper, say of six or eight inches in width, into a long sheet and then, after being annealed, it was taken to a slitting machine and slit into square rods. These rods were tapered by means of a hammer, in order that they might be inserted far enough through the drawing die to be grappled on the opposite side, after which they were ready to be drawn into wire. This method of starting with a square rod had a distinct disadvantage for the reason that the corners were likely to lap and fold over in the process of drawing, thereby producing flaws or bad places in the wire, these flaws becoming more and more troublesome in the smaller sizes of wire. After having been drawn through a certain number of "holes," the surface of the wire becomes hardened to an extent which requires that it should be annealed before any further reduction in size is practicable. The new process is substantially as follows: —

The copper is received from the smelting works in the form of wire bars, which are approximately fifty-four inches long, with an average diameter of about three and three-fourths inches, and weigh about two hundred pounds each. These are delivered as commercial copper wire bars.

The first operation is to put the bars into what is termed a "continuous furnace," the bars going in at one end of the furnace and taken out at the other. In their passage through they are heated to about 950° Centigrade, at the rate of about two bars per minute.

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The heated bars are then put through a series of grooved rolls. Each succeeding groove being smaller, it results in a reduction of the three and three-fourths inch bar to a diameter of five-sixteenths inches. These are now called rods, and are taken up on a reel in the form of a coil about thirty inches in diameter. These coils are then taken from the hot-rolling department, and are cold at that time. They are then plunged into a bath of sulphuric acid and water for the purpose of removing whatever oxide has been formed in the hot-rolling operation. After about twenty minutes in this solution, the oxide is removed and the rods are then taken and thoroughly washed with clean water under a high pressure from a hose; after which they are immersed in a vat containing a lubricant of tallow and soap. The rods are now ready for the drawing process.

The rods are substantially drawn on what is termed by wire manufacturers a "continuous wire drawing machine." That is to say, the five-sixteenths inch rod goes in at one end of the machine, and, after passing through several dies, each one reducing the diameter and hardening the wire, it finally is drawn around a block to the finished size, say .104″.

In making this reduction, the copper is reduced in diameter from #1 wire gauge to #12 wire gauge, or, in technical terms, the wire is "eleven numbers hard." This process gives the wire the greatest amount of tensile strength possible from commercial copper and yet preserve its elasticity. The cost of production is enormously reduced by the new process. Whereas, under the old process, a very skilled workman was required for each single drawing, an attendant is now able to care for several continuous drawing machines that are run at a speed, unapproachable by the old method. In the smaller sizes of wire, diamond dies are employed which, in themselves, represent a very considerable investment.

Commercial copper in its soft state has a tensile strength of about 28,000 pounds per square inch, with an elongation of about thirty-six per cent., and by the cold-drawing process above described, the tensile strength is increased by each number drawn, and the elongation is reduced; therefore when the

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copper wire is drawn eleven numbers hard, it has a tensile strength of about 64,600 pounds per square inch, with an elongation of about one per cent. The wire is then taken from the wire-drawing blocks, so-called, and is carefully inspected for tensile strength, elongation, torsion and conductivity. The inspected wire is then carefully packed by wrapping each coil with burlaps, so that it does not become bruised or damaged in any way by transportation.

The cost of hard drawn copper wire fluctuates with the price of ingot copper, and at present writing is quoted at sixteen cents per pound. The relative cost of copper and iron wire, say of #12, is three and three-fourths cents for iron and sixteen cents for copper.

The advantage of copper over iron, besides what is shown in the table below, is that it is practically indestructible except from mechanical injury, and, if it receives mechanical injury, it can be made over into new wire at a cost of about two cents per pound, while iron, which is subject to rapid deterioration from rust, is worthless when taken down.

The output of hard drawn copper wire has steadily increased from year to year.

The comparative properties of #12 N. B. S. gauge copper and iron wire are given in the following tables, this being the size in the largest general use as telephone toll line conductors.

No. 12 N. B. S.	Diameter in Mills	Resistance per Wire Mile 68° F. Ohms	Inductance per Pair Mile Milhenries	Effective Resistance per Wire Mile Ohms	Electro Static Capacity per Pair Mile Micro microfarods	Miles equal to 1 Mile Hard Drawn Copper for Telephone Transmission
Soft copper	104	5.1	3.66	5.1	8220	1.02
Hard drawn copper	104	5.2	3.66	5.2	8220	1.00
Iron B. B.	104	36.0	18.00	47.0	8220	0.26

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No. 12 N. B. S.	Diameter in Mills	Weight per Wire Mile lbs.	Tensile Strength in Pounds	Torsion in 6 inches	Elongation Per cent.
Soft copper	104	173	290	50–75	40.
Hard drawn copper	104	173	550	25–45	1.
Iron B. B.	104	153	450	45	18.

The above figures represent average commercial conditions. The soft drawn copper wire is assumed to have a conductivity of 99 per cent. of that of pure soft copper, while that of the hard drawn is 97 per cent.

The wires of a pair are supposed to have a separation of 12 inches on centers. In calculating the inductance and effective resistances, a frequency speed ($2\pi n$) of 5,000 has been taken, while assuming a permeability of 100 for the iron wire.

Much of added interest could be written were the writer to disregard the individual trade secrets that must be respected.

The following manufacturers are producing hard drawn copper wire:

John A. Roebling's Sons Company,
Coe Brass Manufacturing Company,
Ansonia Brass and Copper Company,
Holmes, Booth & Haydens Company,
National Conduit and Cable Company,
American Steel and Wire Company,
The Waclark Wire Company,
Standard Underground Cable Company,
American Electrical Works,
The Bridgeport Brass Company.

I am indebted to the officers of these companies, and also to Mr. Charles F. Brooker and Dr. Hammond V. Hayes, for valuable assistance in the preparation of this paper.

PINE ORCHARD, CONNECTICUT,
Nov. 1st, 1905.

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THE PLANO ARCH.

By John P. Hazen Perry, S. B. '03.
Jun. Am. Soc. C. E.

Three quarters of a mile east of Plano, Illinois, the main line of the Chicago Burlington and Quincy R. R. crosses Big Rock Creek. At the crossing point the stream flows through a valley about a thousand feet wide and sixty feet deep. Since the construction of the railroad in 1852–53, five bridges, including the present structure, have spanned the valley. The last bridge (Fig. 3)—built in 1882 to replace a 185 ft. Howe truss—consisted of a main span of a square ended, pin-connected, deck Pratt truss 99 ft. long, and four deck-girder spans, two at either end; making a total length of 275 ft. This structure was deemed too light for modern traffic requirements and in August, 1903, the contract was let for the replacing of this bridge with a concrete arch.

The plans of the new bridge called for an arch of 75 ft. clear span with wing walls giving a total length of 210 feet. The arch is 3 feet thick at the crown and is heavily re-inforced throughout with Johnson corrugated bars. The bridge was designed to carry the heaviest loads and was calculated according to Mr. A. L. Johnson's formulae for reinforced concrete.

This paper will deal with the construction of the bridge. Before going into an account of the work in its progressive stages a few notes on the materials used might be appropriate.

The concrete was used in two proportions. For all parts of the bridge, except the arch ring, the mixture was 1–3–6, cement–sand–stone; for the arch ring 1–2–4 was used. The cement was, for all except a small portion of the foundations, "Owl" Brand from La Salle, Ill. The sand came from the great Steward pit, an opening in the glacial drift which overlies all this part of Illinois. Stone was furnished by Doleese & Shepard from their Hawthorne quarries just out of Chicago. The

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contractor obtained permission to use gravel in the proportion one of gravel to two of stone for all parts of the bridge except the arch ring. The "mix" then became 1–3–2–4, cement–sand–gravel–stone. The gravel was brought from the Steward pit. At first the product of the pit was screened to give the proper proportions of sand and gravel, 3–2. After screening perhaps 500 yards it was found that the pit was yielding almost exactly the proportions desired and no further screening was resorted to except to get the sand for the arch ring.

The mixture used was very wet, water being added to the mixer until the concrete was like heavy slush. Care was taken to make the little concrete tram cars absolutely tight at the bottom so that none of the liquid "fine stuff" — cement and sand — should be lost in transit from the mixer to the forms. This very wet mix gave, with but ordinary care in spading the stone away from the forms, a most excellent face sufficiently smooth nearly everywhere to show the grain of the wood in the forms. Upon resuming work on the top of concrete, already hard, wire brushes and a powerful hose were used to remove "la laitance," the peculiar scum which rises to the surface of very wet concrete and works so adversely to the bonding of the new concrete with the old.

The reinforcing bars were corrugated steel bars seven-eighths in. square and three-fourths in. square. In all 60 000 lbs. were used in the bridge giving a length of 30 000 ft. The bars are shown in Fig. 2. They came in lengths averaging about 25 ft. requiring two men to handle each piece. No attempt was made to paint them or protect them from rust, it being thought that the bond obtained by rough rusty bars was better than with painted ones.

The method adopted for building the arch without interrupting traffic was unique. The C. B. & Q. R. R. being double tracked the natural way of handling the problem would have been to discontinue the use of one track throwing all traffic on the other and use the first track to construct half of the new bridge — transfer all traffic to the new bridge and use the second track, now abandoned for completing the job. The

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railroad company in this instance, however, insisted on maintaining double track traffic. It was therefore decided to leave the old bridge intact, except for the lateral and sway bracing, and build the arch span up through the truss rods. Fig. 2 shows the forms for these holes. Falsework was erected on the deck of the arch and traffic thrown thereon. The pins connecting the truss members were knocked out; the rods drawn up through the holes by a derrick and the holes concreted, the bridge filled,

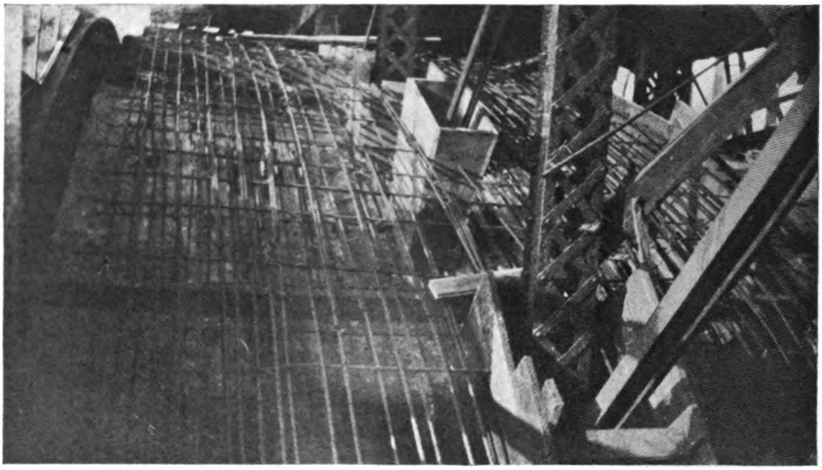

FIG. 2.

and allowed to settle; the track ballasted up and the centering and falsework removed.

The railroad company began operations in May, 1903, by digging the pier pits and driving the foundation piles. The old masonry piers (Fig. 3) were to be incorporated in the skew back and foundations of the new arch. Small sheet-piling cribs were built and excavations carried to five feet below stream bed and the concrete brought up about water level.

In August the contractor took charge of the work.

His force was organized under two foremen into a carpenter gang and a concrete gang. Eventually the carpenter foreman took charge of the work, supervising everything. For mixing

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his concrete the contractor used both an "Olsen" and a "Drake" mixer. Power was furnished by an upright boiler. For transporting the concrete, tram cars of about a yard and a half capacity were used. Temporary tracks were built from the mixer to the place of deposit and the cars run out on them by man power. For handling his lumber the contractor made use of the high fill at one end of the bridge. (See Fig. 4.) The timber was dumped from the railroad cars on to the side of this fill whence they rolled out on a meadow practically in position for cutting and framing. When the bents and centers were ready for placing they were pushed into the stream, floated down against the falsework piles and hoisted into position with block and tackle.

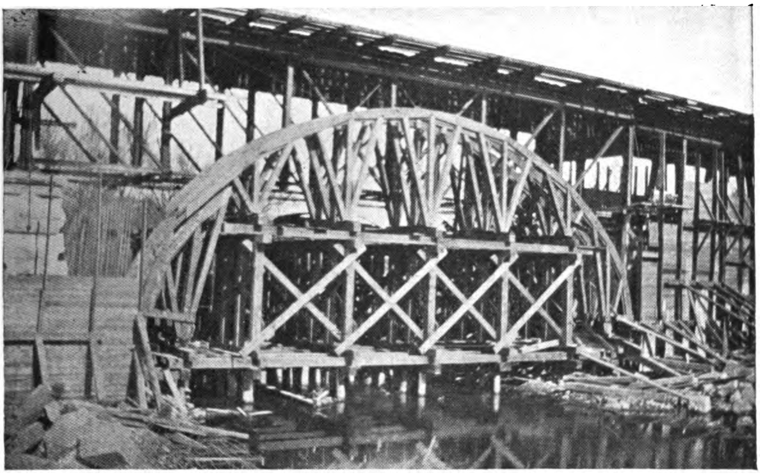

FIG. 3.

The falsework (Fig. 3) consisted of heavy bents resting on piles. On the falsework were the centers. The pile caps, falsework and centers were made of 12 in. by 12 in. timber. The centers were made in fan shaped sections and were hoisted into place and wedged to exact position. Fig. 3 shows three of the arch rings in place and nearly all connected up. The wedges were of oak beveled both ways and well soaped. When three of the twelve centers were in position they conformed to

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the line of the intrados of the arch and checked by plumbing down from a base line laid out on the edge of the bridge ties on the deck of the old bridge. From this base line ordinates were measured to the points on the arch ring and all tightened up securely. From these centers as a guide the remaining ones were set and lagged. The lagging was of 3 in. stuff planed to a bevel to make tight joints. The carpenter work was excellent, the centers checking very well indeed.

While the falsework and centers were being made ready the contractor started work on the concrete and on the cutting of the masonry piers. The latter presented an unexpected difficulty. The stream faces of the piers were to be cut into steps, eleven in number, and into the base of each step were to be set 4 ft. corrugated bars; the idea being to bond the arch skew-back and foundation with the old pier, there being an opportunity for unequal settlement and consequent cleavage. The contractor told the writer that he had estimated the cost of this stone cutting at one hundred dollars and the time at two weeks. It actually came to one thousand dollars and took eight weeks to complete. The trouble lay in the character of the stone constituting the piers. They were built in 1882 of Aurora limestone, which is famous locally for the way it hardens with exposure. When the stone-cutters undertook to cut the steps specified they found that between the hardness of the stone and the way in which it was bound in courses they could do nothing but chip the surface in small spalls. An Ingersoll-Sargent drill was called into use for drilling the 4 ft. holes for the main reinforcing bars coming over the extrados of the arch — and also to cut four steps in the face of each pier by drilling 4 ft. holes at 2 in. centers and taking the rock out with plugs and feathers. The steps that were thus cut were well up on the pier and in order to make a bond below them the face of each pier was cut into prismoidal shaped holes at the joints, the cutting being easier there because of less bonding effect. The nose and back of each pier were also cut to aid the concrete in bonding with the piers. The work at these joints consisted of cutting away alternate

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courses to a depth of about 8″. Fig. 3 shows this work — the back of the pier at the left of the cut.

The general method of placing the concrete was as follows:— The wing walls, one at a time, were brought up to about the elevation of the top of the old piers. At the same time the arch foundations and skew backs were carried up to the springing line. Then the arch was turned and the wing walls carried up to within a few feet of the finish line. The spandrel walls on the arch ring were then brought up to the same level and the

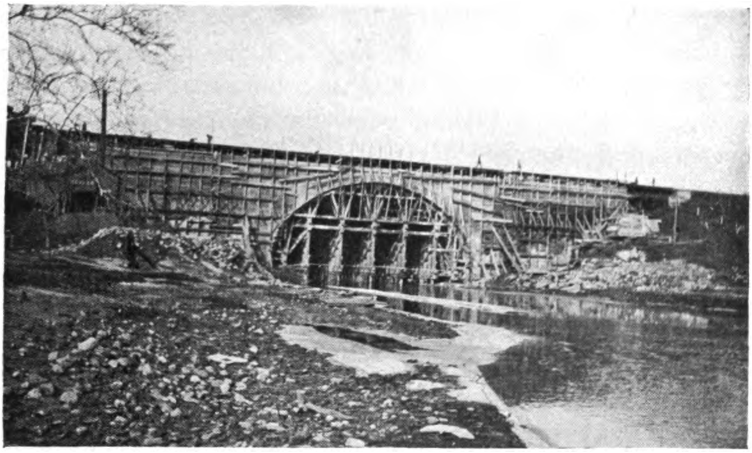

Fig. 4.

remaining few feet of wall and coping put on over the entire length.

The forms for the wing walls were braced by struts from the outside and were wired together as well. The temporary braces were used to hold the forms apart till filled with concrete. The face wall forms were made of 2 by 8 in. tongued and grooved yellow pine plank. The back wall forms were of rough lumber 2 by 8 in. When the wing walls got up so high that struts were no longer practicable knee-bracing was resorted to. Both kinds of bracing are shown in the accompanying cuts. The line of the completed walls was very good — there being scarcely

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any bulging. In all about 500 000 ft. B. M. of lumber was used on this piece of construction and 300 000 ft. of it was available for use on other work at the end of the job.

The arch ring was turned in parallel strips. It was required that there be no transverse joint planes and to fulfill these specifications it was necessary to have continuous work on the ring. This with the plant on the ground was impossible. The daily average of concrete placed was about 90 cu. yds. In the arch ring were about 900 cu. yds. There was not enough labor available to make it possible to run day and night for five days. The arch was therefore divided into several longitudinal strips. Bulkheads were erected on the lagging and molded to form a key between each strip. These bulkheads were braced against the truss members. In filling one of these rings batches were deposited first at one end and then at the other end of the arch — to prevent unequal loading and consequent unequal thrust on the centers. Work was carried on continuously until the arch ring was completed. Only once was it necessary to quit work in the course of turning an arch ring. A blizzard came up during one night, when the ring was about half complete, and effectually clogged the plant — tracks, cars, and men. A radial joint was bulkheaded up and filled to full depth of the arch and the top of the concrete boarded up and left till the storm ceased when work proceeded to the completion of that particular strip.

Most of the concrete was deposited from the top of the old bridge. When the fall was more than fifteen feet chutes were used. If the chute had to be on a slant a curtain door was rigged over the mouth of it to prevent the stone from jumping out away from the fine stuff as it all dropped into the forms. Most of the chutes were of wood hastily knocked together by the carpenters. In turning the arch, however, much use was made of an iron chute or trough which could be moved in among the old truss members and reinforcing bars with facility. The reinforcing rods (Fig. 2) made the shoveling of the concrete very difficult on the drum of the arch. The men handling it had to crouch in between the extrados and intrados bars.

All of the arch ring and the major part of the wing walls were

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built during freezing weather. The precautions taken to avoid freezing of the concrete were simple and effective. The sand and water were heated as much as possible. The former was handled as follows. At the sand pile was laid about 30 ft. of 2-ft. iron stack or thin pipe open at each end with a stack rigged near the center for better draught. A roaring fire was kept in this stack night and day and the sand heaped up over it to a depth of a couple of feet all around. In this way sand was kept very hot, often to a dull red. The water was heated by a steam hose run into a barrel at the mixer. The stone was not heated, care only being taken to keep the stone pile free from snow so that thawing in the middle of the day and freezing at night should not bond the stone into an ice heap. In the forms a steam hose was kept going. Its use was varied. In the arch ring there were the reinforcing rods sticking out of the concrete which acted as so many pipes to conduct away the heat. These rods were kept under steam as much as possible, the man with the hose working at the opposite end from where the concrete shovelers were. Further, the concrete in dropping into the forms spattered the rods and the forms and this spatter immediately froze and the steam hose was about the only thing which would remove it. Then also after a snow storm the steam hose removed the ice from the forms very quickly. One of the arch rings was turned one night when the temperature was 8° below zero. The concrete showed no signs of freezing. A thermometer put with its bulb just beneath the surface of concrete which had been in position three hours registered 35° and when pushed down about four inches into the concrete the reading was 68°.

When the arch ring was completed it was deemed advisable to heat it. Concrete sets very slowly when frozen solidly. Once it gets its initial set, say inside of four hours after mixing, it is safe from harm from freezing. It will not set up hard until the frost is out of it. On this piece of work the arch ring was completed in January and the spandrel walls a month later. The railroad company was in a hurry to get unrestricted use of the bridge and heating was resorted to to give summer conditions about the arch and thus allow it to set and be ready to take its load.

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The falsework just at the bottom of the centers was floored over and the ends of the room thus made by the floor and the arch, were boarded up and all tar-papered to keep out the wind. In this loft like space, as close to the arch as possible, was 5000 feet of steam piping. An old locomotive boiler was brought from the Aurora shops and set up temporarily to supply steam for the heating plant. The top of the arch was enclosed by means of the spandrel walls and partitions at the ends and between the spandrel walls and the floor of the old bridge. With this complete housing in of the arch a temperature of from 96° over the arch to 100° under the arch was maintained for a mouth completely drying the arch.

When traffic was thrown on the temporary bents on the arch and the old bridge removed by the "wrecker" the holes in the arch ring were filled with concrete and the filling of the bridge started. The dirt for this purpose came from widening a nearby railroad cut. When the falsework was removed no settlement was observable in the crown of the arch.

The plans of this bridge were drawn in the office of Chief Engineer W. L. Breckenridge under the direction of C. H. Cartlidge, Bridge Engineer, the contractor was G. H. Scribner, Jr., of Chicago. The writer was in charge of the work for the railroad company.

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THE DISTRIBUTION OF PRESSURE AND CURRENT OVER ALTERNATING-CURRENT CIRCUITS.

By A. E. Kennelly, D. Sc.

When an alternating-current circuit for the transmission of power is operated at any of the usual commercial frequencies not exceeding 60 cycles per second, it is well known that the distribution of pressure and current in the circuit may be computed, within a degree of accuracy sufficient for practical purposes, by collecting all of the capacity distributed along the lines

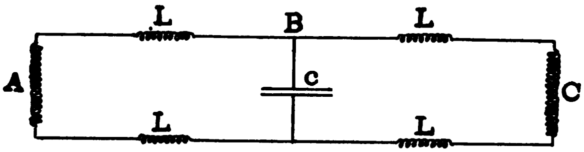

Fig. 1. Diagram of an Alternating-Current Circuit with the entire Line Capacity centered at B, and the resistance and inductance divided between the four choking-coils L, L, L, L.

into a single lump, or imaginary condenser c, midway along the circuit, as indicated at B in Fig. 1, and collecting the distributed resistance and inductance on each side of this condenser into imaginary choking coils L, L, L, L. By this method of dealing with the circuit, the line becomes a mere collection of condenser and choking-coils. The drop in pressure over the lines, as a whole, may then be determined for any given alternating-current load, even for the longest circuits at present in use for electric power transmission.

As a convenient modification of the above plan, the metallic circuit of Fig. 1 may be regarded as a pair of single-wire circuits, each with a perfectly conducting ground-return circuit, as shown in Fig. 3, and each having twice the localized condenser capacity ($2c$), compared with the condenser (c) of Fig. 1. Each ground-return circuit in Fig. 3 has also half the e. m. f. and

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impedance of the metallic-return circuit in Fig. 1. The process of transition in conception from the single metallic-return circuit of Fig. 1 to the equivalent pair of independent ground-return

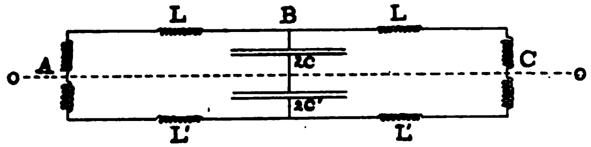

Fig. 2. Division of the circuit of Fig. 1 into two equal and symmetrical portions about the neutral mid-plane 00 of zero potential.

circuits of Fig. 3, is indicated in Fig. 2; where the metallic circuit is first divided symmetrically about a neutral midplane of zero potential, or earth potential.

It is well known that any interlinked multiphase system of circuits may likewise be resolved into independent single-phase single-wire lines with imaginary perfectly conducting ground-return circuits; so that it suffices to solve the problem of pressure and current-distribution for a simple single-phase single-wire ground-return circuit in order to determine the corresponding solution for any two-wire metallic circuit; or for any interlinked multiphase and multiple-wire circuit. For

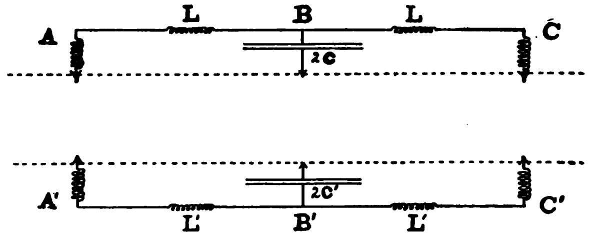

Fig. 3. Analysis of the double-wire circuit of Fig. 1 into two equivalent single-wire circuits A, B, C and A′ B′ C′, each having twice the condenser capacity of the circuit in Fig. 1.

this reason only such single-phase single-wire circuits as are indicated in Fig. 3, need be considered in what follows.

As already stated, the treatment of an alternating-current circuit in the manner of Fig. 3 is permissible for the low frequencies of power transmission. This is because the wave-

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length of alternating current at such frequencies is ordinarily hundreds of miles long; so that the longest circuits in use are but fractions of a wave-length, or are short compared with a wave-length. When an alternating-current circuit is short compared with the length of impressed waves, all parts of the circuit present phenomena of nearly the same phase. It becomes unnecessary to enquire into the relative phase of current and pressure at different points along the line, and the line may safely be treated as equivalent to a pair of choking coils with a condenser connected to ground between them.

When, however, the frequency is considerably increased, either by the use of higher impressed frequencies, as in telephony; or in the consideration of harmonics incidental to the usual low fundamental frequencies of power transmission, the wave-length of the current is correspondingly shortened, and the line may no longer be short compared with the impressed wave-length. Under such conditions the treatment by the method indicated in Figs. 1–3 is inadequate and may involve considerable error. A more rigorous analysis must be substituted which deals with the distribution of resistance, inductance, leakance and capacity, in their natural association. Moreover, this more rigorous method has to be resorted to, even for low frequencies, when a higher degree of accuracy is required in the solution of the problem than is necessary for ordinary engineering purposes. The more accurate method is well known under a variety of mathematical forms.* It is, however, the object of this paper to present the method in the form of hyperbolic trigonometry, which appears to be the simplest and most direct. This form follows immediately from the corresponding treatment of continuous-current circuits of uniform resistance and leakance in

* Heaviside's "Electrical Papers." London, 1892. Vol. II, p. 248.

M. Leblanc, Trans. Am. Inst. El. Engrs. June, 1902. Vol. XIX, pp. 759–768.

M. I. Pupin, Trans. Am. Inst. El. Engrs. Vol. XVII, pp. 445–513. May, 1900.

G. A. Campbell, "Phil. Mag." March, 1903.

G. Roessler, Fernleitung von Wechselströmen. 1905.

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the steady state; so that the formulae which control continuous current circuits * apply also, with extended meaning, to alternating-current circuits, just as Ohm's law applies not only to continuous-current circuits, but also to alternating-current circuits, when impedance is substituted for resistance in the formula. $I = E/R$.

Every circuit carrying alternating currents of one frequency possesses an *attenuation-constant* a, such that any electric wave of this frequency shrinks in magnitude, or attenuates, to the extent of $\frac{1}{\epsilon^a} = \epsilon^{-a}$ in running unit distance over the circuit. If the wave has, therefore, say a magnitude of unity at a given

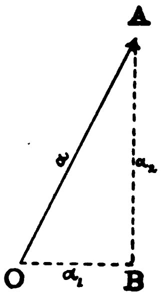

Fig. 4. Analysis of the vector attenuation-constant $OA = a$ into the real part $OB = a_1$ and the imaginary part $BA = a_2$.

point in the circuit, and the unit of length is a mile; then the magnitude of the wave will be ϵ^{-a} after running one mile, $\epsilon^{-a} \cdot \epsilon^{-a} = \epsilon^{-2a}$ after running two miles, and ϵ^{-La} after running L miles. Since the exponent La must be some number, and L is a length, a has the dimensions $\frac{1}{\text{length}}$.

The attenuation-constant a is a complex quantity of the type

$$a = a_1 + ja_2 \qquad \text{per mile or kilometre} \qquad . \quad (1)$$

so that a_1 is the real part of the attenuation constant and a_2 the imaginary part, as indicated in Fig. 4; where

$$a = \sqrt{a_1^2 + a_2^2} \; \underline{| \tan^{-1}\frac{a_2}{a_1}} = a_1 + ja_2 \qquad . \quad . \quad (2)$$

* A. E. Kennelly, HARVARD ENGINEERING JOURNAL. May, 1903. pp. 135–168.

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If then a wave in running one mile shrinks in the ratio ϵ^{-a}, it becomes multiplied by the factor $\epsilon^{-a} = \epsilon^{-(a_1 + ja_2)} = \epsilon^{-a_1} \cdot \epsilon^{-ja_2} = \epsilon^{-a_1} \underline{|\ a_2}$. That is, the magnitude alters by $\epsilon^{-a_1} = \frac{1}{\epsilon^{a_1}}$ and the phase is retarded by ϵ^{-ja_2} or by a_2 radians, or by $a_2 \left(\frac{180}{\pi}\right)$ degrees. In two miles, the wave will have shrunk in the ratio $\epsilon^{-2a} = \epsilon^{-2a_1} \underline{|\ 2a_2}$; or in the ratio $\frac{1}{\epsilon^{2a}}$ with a phase retardation of $2a_2$ radians. Similarly, after L miles, the wave will have shrunk $\epsilon^{-La} = \epsilon^{-La_1} \underline{|\ La_2}$ or in the ratio of magnitude by $\frac{1}{\epsilon^{La_1}}$, with a phase retardation of La_2 radians. The retardation of phase in one complete wave-length λ miles will be 2π radians, and consequently the wave-length is determined by the relation

$$2\pi = \lambda a_2 \qquad \text{radians} \quad . \quad . \quad . \quad . \qquad (3)$$

or $$\lambda = \frac{2\pi}{a_2} = \frac{6.283}{a_2} \qquad \text{miles or kilometres} \quad . \qquad (4)$$

It is evident that the attenuation constant a of the line, at the impressed frequency under consideration, consists of a real part a_1 affecting the shrinkage in magnitude, and an imaginary part a_2 affecting the shrinkage in phase, such that the wave-length is the quotient of a_2 into 2π. For this reason the imaginary component a_2 is sometimes called the *wave-length constant* of the circuit for the frequency considered.

Moreover, the velocity, rate of advance, or speed of propagation, of the electric waves over the circuit is determined by the relation

$$v = \frac{\lambda}{T} \qquad \text{miles or kilometres per second} \quad . \qquad (5)$$

where T is the periodic time, in seconds, of the alternating current. If n be the frequency of the impressed e. m. f. in cycles per second, $T = \frac{1}{n}$ seconds . . . . . (6)

and if the angular velocity of the impressed e. m. f. be

$$\omega = 2\pi n = \frac{2\pi}{T} \qquad \text{radians per second} \quad . \qquad (7)$$

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Then $v = \lambda n = \frac{\lambda \omega}{2\pi}$ miles or kilometres per second (8)

Or substituting (4)

$$v = \frac{2\pi}{a_2} \cdot \frac{\omega}{2\pi} = \frac{\omega}{a_2} \quad \text{miles or kilometres per second} \quad (9)$$

On plain aerial wires it will be found that v tends to approach 3×10^5 kilometres per second, or 1.86×10^5 miles per second, the velocity of light in air. In plain underground wires, *i. e.*, underground wires not artificially loaded with inductance, v tends to a lower value, of the order 10^5 kilometres per second, the velocity of radiation in the rubber, paper, or other dielectric employed. With either aerial or underground wires which have been artificially loaded with inductance, the velocity v may be reduced to a small fraction of the free dielectric velocity.

As an example of the above principles, we may consider an aerial line consisting of two # 10 A. W. G. copper wires (diameter 0.1019″ or 0.2589 cm.), interaxially separated by a distance of one foot (30.48 cms.). In this line, the resistance r will be 10.6 ohms per loop-mile = 6.586 ohms per loop kilometre; inductance l will be 3.676 millihenrys per loop-mile = 2.284 millihenrys per loop kilometre; capacity c will be 0.008018 microfarads per loop-mile = 0.004982 microfarads per loop kilometre. Referring these to the equivalent single-wire lines of Fig. 3, each has resistance r of 5.3 ohms per wire-mile = 3.293 ohms per wire-kilometre; inductance l of 1.838 millihenrys per wire-mile = 1.142 millihenrys per wire-kilometre; capacity c of 0.01604 microfarad per wire-mile = 0.009964 microfarad per wire-kilometre. The insulation of the wires may be regarded as practically perfect, or the leakance $g = 0$.

The formula for the attenuation constant is

$$a = \sqrt{(r + jl\omega)\ (g + jc\omega)} \quad \text{per mile or kilometre} \quad (10)$$

where r is the resistance, ohms per mile or kilometre

" l is the inductance, henrys per mile or kilometre

" g is the leakance, mhos per mile or kilometre

" c is the capacity, farads per mile or kilometre

" j is $\sqrt{-1}$

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and ω is $2\pi n$, the angular velocity of the impressed e. m. f. in radians per second.

It does not matter whether the constants r, l, g and c are taken from the loop-mile (as in Fig. 1) or from the wire-mile (as in Fig. 3). The same value of a will be found in either case if the values of these constants appropriate to each assumption are inserted in the formula. On the loop-mile basis, the values of r and l will be doubled and that of g and c single. On the wire-mile basis, r and l will become single while g and c will be doubled. The product $(r + jl\omega)\ (g + jc\omega)$ will thus be constant.

In this instance taking the values per wire mile, we obtain for the frequency $n = 200$ or $\omega = 1256.6$ radians per second.

$$
\begin{aligned}
a &= \sqrt{(5.3 + j\ 2.31)\ (0 + j\ 2.015 \times 10^{-5})} \\
&= \sqrt{(5.782\ \underline{|\ 23°.34'})\ (2.015 \times 10^{-5}\ \underline{|\ 90°})} \\
&= \sqrt{1.165 \times 10^{-4}\ \underline{|\ 113°.34'}} \\
&= 1.079 \times 10^{-2}\ \underline{|\ 56°.47'} = 0.010{,}79\ \underline{|\ 56°.47'} \text{ per mile} \\
& \qquad a_1 + ja_2 = 0.005{,}914 + j\ 0.009{,}028.
\end{aligned}
$$

The real attenuation constant a_1 is thus 0.005,914 per mile.

The wave-length constant a_2 is 0.009,028 radians per mile.

The wave-length λ by (4) is $\dfrac{6.283}{0.009{,}028} = 695.6$ miles.

The wave-velocity v by (9) is $\dfrac{1256.6}{0.009{,}028} = 139{,}200$ miles per second.

Since $\epsilon^{-La_1} = 0.5$ when $La_1 = 0.693{,}15$ . . (11)

the waves will have shrunk to half amplitude after running a distance of $\dfrac{0.69315}{a_1}$ miles (or kilometers). This distance which waves can cover before shrinking to half size may be called the *semi-amplitude range* and be denoted by $L_{\frac{1}{2}}$. In the case here considered $L_{\frac{1}{2}} = \dfrac{0.693{,}15}{0.005{,}914} = 117.2$ miles.

If we insert the kilometre values of r, l, g and c in the formula, we obtain $a = 0.006{,}706\ \underline{|\ 56°.47'} = 0.003{,}673 + j0.005{,}61$ per kilometre; from which the real attenuation constant is 0.003,673 per kilometre; the wave-length constant 0.005,61

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radians per kilometre; the wave length λ, by (4) is $\frac{6.2832}{0.005,61} =$ 1,119.5 kilometers; the wave-velocity v by (9) is $\frac{1,256.6}{0.005,61} =$ 224,000 kilometres per second; the semi-amplitude range $L_{\frac{1}{2}}$ by (11) is $\frac{0.693,15}{0.003,673} = 188.7$ kilometres. The velocity v is in this instance only about 75 per cent of that in free air, mainly owing to the ohmic resistance in the wire. If the wire be assumed resistanceless, or of infinite conductivity, $r = 0$ in (10) and the velocity v would become 296,400 kilometres per second; or 98.8 per cent. of that of free waves in air.

Formula (10) shows that as the impressed frequency increases, the vector attenuation-constant also increases. Thus, in kilometre units, the line above considered has the following values of vector attenuation-constant, real attenuation-constant, wave-length-constant, wave-length, wave-velocity, and semi-amplitude range.

Table I.

For single-line copper wires #10 A. W. G. 0.2589 cm. diam. at interaxial distance of 30.48 cms. $r = 3.293$, $l = 0.00142$, $g = 0$, $c = 0.996,4 \times 10^{-8}$ kilometre units.

n	ω	α		α_1	α_2	λ	v	%	$L_{\frac{1}{2}}$
cycles per second	radians per second	vector attenuation constant per kilometre		real attenuation constant per kilometre	radians per kilometre	kilometres	kilometres per second	free air velocity	kilometres
7.96	50	0.001,281	45°.30′	0.000,898	0.000,913,4	6,880.	54,750	18.25	772.2
15.92	100	0.001,812	46°	0.001,259	0.001,303	4,822.	76,750	25.6	550.5
39.80	250	0.002,869	47°.29′	0.001,939	0.002,114	2,972.	118,300	39.4	357.4
79.60	500	0.004,080	49°.55′	0.002,627	0.003,122	2,012.	169,154	53.4	263.8
159.2	1,000	0.005,892	54°.34′	0.003,417	0.004,80	1,309.	208,330	69.4	202.8
200.	1,257	0.006,706	56°.47′	0.003,673	0.005,61	1,120.	224,000	74.7	188.7
398.	2,500	0.010,42	65°.28′	0.004,326	0.009,48	662.8	263,700	87.9	160.2
796.	5,000	0.018,12	75°.01′	0.004,684	0.017,51	358.8	285,600	95.5	148.0
1,592.	10,000	0.034,42	81°.57′	0.004,819	0.034,08	184.3	293,430	97.8	143.8
15,920.	100,000	0.337,4	89°.11′	0.004,859	0.337,3	18.62	296,470	98.8	142.6

Fig. 5 indicates by the curved line OAA, the locus of the vector attenuation-constant for different frequencies, according to the entries of Table I. It is evident that for frequencies

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above 400 cycles per second the real attenuation-constant increases slowly and always lies theoretically below 0.005; while the wave-length-constant goes on increasing almost in direct proportion to the frequency.

In cable circuits, when the capacity is relatively large and the inductance very small, the attenuation-constant vector follows a different course. Thus, taking telephone cable consist-

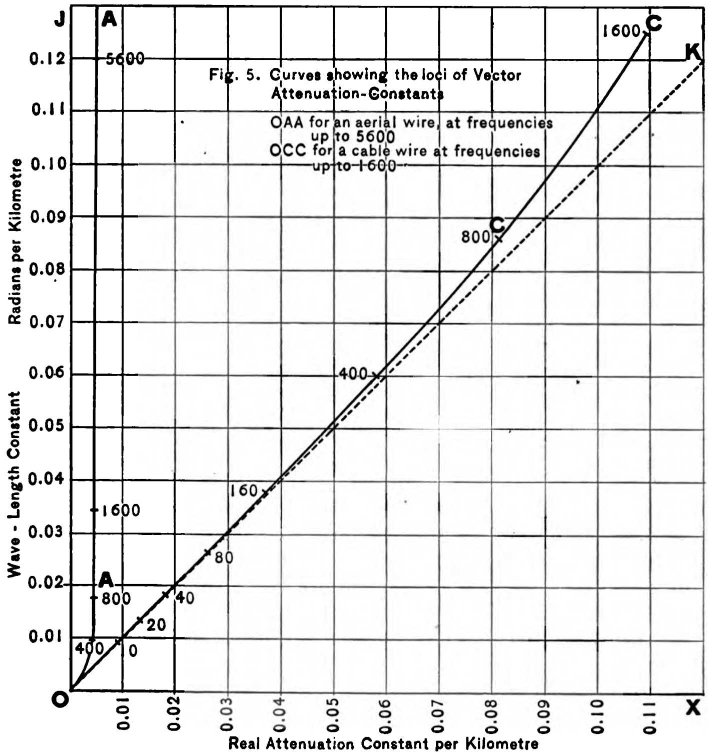

Fig. 5. Curves showing the loci of Vector Attenuation-Constants

OAA for an aerial wire, at frequencies up to 5600
OCC for a cable wire at frequencies up to 1600

ing of twisted pairs of #19 A. W. G. paper-covered copper wire (diameter 0.035,89″ or 0.091,2 cm.) with a resistance per loop-mile of 90 ohms, a capacity per loop-mile of 0.08 microfarad and an inductance per loop-mile of 0.563 millihenry, the corresponding single-wire values per kilometre are: —

$r = 27.96$ ohms; $l = 0.000,35$ henry; $g = 0$.

$c = 0.994 \times 10^{-}$ farad.

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With these values we obtain by formulae (4), (9), (10) and (11) Table II.

Table II.

For single-line copper wires in twisted pair cables #19 A. W. G. 0.0912 cm. diam.

n cycles per second	ω radians per second	a attenuation constant per kilometre		a_1 real attenuation constant per kilometre	a_2 radians per kilometre	λ kilometres	v kilometres per second	% free air velocity	$L_{\frac{1}{2}}$ kilometres
9.95	62.5	0.013,18	45°.0′	0.009,32	0.009,32	674.1	6,706	2.2	74.38
19.9	125	0.018,62	45°.0′	0.013,17	0.013,17	477.1	9,492	3.2	52.63
39.8	250	0.026,36	45°.06′	0.017,90	0.017,96	349.8	13,920	4.6	38.72
79.6	500	0.037,24	45°.10′	0.026,26	0.026,41	237.9	18,930	6.3	26.39
159.2	1,000	0.052,72	45°.22′	0.037,04	0,037,52	167.5	26,650	8.9	18.72
397.9	2,500	0.083,35	45°.54′	0.058,0	0.059,86	105.0	41,760	13.9	11.95
796.	5,000	0.118,0	46°.48′	0.080,79	0.086,02	73.04	58,130	19.4	8.58
1592.	10,000	0.167,4	48°.34′	0,108,8	0.125,5	50.06	79,670	26.6	6.37

The locus of these vector attenuation-constants is shown in Fig. 5 by the curve OCC. It is clear from the Figure that when a line has relatively large inductance with relatively low capacity and resistance, the vector attenuation-constant approximates to the straight line OJ, with a correspondingly small real attenuation constant. When, however, the capacity and resistance are large and the inductance small, the vector attenuation constant approximates to the straight line OK inclined 45° to OJ and OX. The real attenuation-constant, as found by the projection of the vector upon OX, will then be relatively large and will approximate in magnitude to the value

$$a_1 = \sqrt{\frac{cr\omega}{2}} \qquad \text{per mile (or kilometre)} \qquad (12)$$

For the telephone cable above considered, this becomes

$$a_1 = 0.001{,}179\sqrt{\omega} \qquad \text{per kilometre} \qquad (13)$$

For a submarine telegraph cable with 3.041 ohms per naut, 0.3728 microfarad per naut and negligible inductance

$$a_1 = 0.000{,}574{,}5\sqrt{\omega} \qquad \text{per kilometre} \qquad (14)$$

In any line the real attenuation constant tends to a limiting value as the frequency increases. This limit is

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$$a_1 = \frac{\frac{r}{2}}{\sqrt{\frac{l}{c}}} \qquad \text{per mile or kilometre.} \qquad (15)$$

Thus for the aerial wires above considered, $\sqrt{\frac{l}{c}} = 338.6$ ohms and $\frac{r}{2} = 1.647$ ohms per kilometre. Consequently the limiting value of the real attenuation constant is $\frac{1.647}{338.6} = 0.004{,}864$ per kilometre. For the cable wires above considered, $\sqrt{\frac{l}{c}} = 59.34$ ohms, and $\frac{r}{2} = 13.98$ ohms per kilometre. Consequently the limiting value is $\frac{13.98}{59.34} = 0.235{,}6$ per kilometre. These results, taken in connection with Tables I and II and the curves of Fig. 5, demonstrate clearly the advantages possessed by aerial wires over cabled wires in the transmission of high-frequency alternating-current waves, as in telephony.

Initial Sending-End Impedance. Every line or circuit possesses a particular impedance which it offers to impressed alternating-current waves of a given frequency at the outset of their career. The impedance is offered at the sending end of the line and is, therefore, a sending-end impedance, as distinguished from the impedance offered at the receiving end. Moreover, it is an *initial* sending-end impedance, or an impedance to the freshly outgoing waves, as distinguished from the impedance presented at the sending end to the entire assemblage of waves finally flowing into the circuit after a steady state has been attained, and when many attenuated reflections of waves, that have run to and fro over the circuit, may be included along with freshly outgoing waves from the alternating source. The initial sending-end impedance may be denoted by the symbol z_0. The formula is

$$z_0 = \sqrt{\frac{r + jl\omega}{g + jc\omega}} \qquad \text{ohms} \quad . \quad . \quad . \quad (16)$$

For very high frequencies, and also for moderate frequencies in

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cases where r and g are small with respect to $l\omega$ and $c\omega$ respectively, the value of z_0 tends to the limit

$$z_0 = \sqrt{\frac{l}{c}} \qquad \text{ohms} \quad . \quad . \quad . \quad . \qquad (17)$$

which value is sometimes called the surge-impedance of a line; or the impedance that the line tends to offer to its own free oscillations or surges.

The sending-end impedance of a metallic-circuit or looped conductor as in Fig. 1 is double that of a single-wire conductor as in Fig. 3. Whereas, therefore, the attenuation constant of a circuit is numerically the same, whether we consider the loop-mile or the wire-mile, the sending-end impedance of the loop-mile is double that of the wire-mile. As, however, the impressed e. m. f. on the loop circuit of Fig. 1 is double that impressed on each line in Fig. 3, the current flowing will be the same in either case. Table III sets forth the initial sending-end impedance of the aerial line already considered.

Table III.

Initial Sending-End Impedance per Single Wire for a pair of #10 A. W. G. Copper wires (0.1019″ or 0.2589 cm.) interaxially separated 1 foot (30.48 cms.) at different impressed frequencies.

n cycles per second	ω radians per second	z_0 vector ohms		z_0 complex quantity ohms	
7.95	50	2,570.	$-44°.30'$	1,833.	$-j$ 1,801
15.9	100	1,818.	$-44°.00'$	1,308.	$-j$ 1,216.
39.8	250	1,152.	$-42°.32'$	849.	$-j$ 778.8
79.6	500	819.0	$-40°.05'$	626.7	$-j$ 527.4
159.2	1,000	591.4	$-35°.26'$	481.9	$-j$ 342.9
397.9	2,500	418.4	$-24°.32'$	380.6	$-j$ 173.7
795.8	5,000	363.7	$-14°.59'$	351.3	$-j$ 94.02
1,592.	10,000	345.4	$-8°.03'$	342.0	$-j$ 48.36
7,958.	50,000	338.8	$-1°.39'$	337.4	$-j$ 9.76
15,920.	100,000	338.7	$-0°.50'$	338.5	$-j$ 4.93

The preceding table expresses the impedance z_0 both as a vector and as a complex quantity. Thus at the frequency of 795.8 cycles per second (5,000 radians per second) the impedance z_0 is $363.7 \,\overline{|\,14°.59'} = 351.3 - j94.02$ ohms for each wire; so that the circuit would offer $727.4 \,\overline{|\,14°.59} = 702.6 - j188.0$ ohms.

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The curve AA in Fig. 6 gives the locus of z_0 in accordance with the entries of the preceding table. The impedance diminishes both in magnitude and in phase-angle as the frequency is increased. Above 800 cycles per second, however, the diminution is very small.

The broken curve CC in Fig. 6 gives the locus of z_0 for each wire of the twisted cable pairs above considered, in accordance with the entries of Table IV.

Table IV.

Initial Sending-End Impedance per Single Wire for a twisted pair of #19 A. W. G. copper wires paper covered in cable.

n cycles per second	ω radians per second	z_0 vector ohms		z_0 complex quantity ohms	
9.95	62.5	2,122.	—45°.	1,500.	$-j$ 1,500.
19.9	125.	1,500.	—44°.58′	1,061.	$-j$ 1,060.
39.8	250.	1,061.	—44°.55′	751.2	$-j$ 749.1
79.6	500.	750.1	—44°.50′	531.9	$-j$ 528.9
159.2	1,000.	530.4	—44°.39′	377.5	$-j$ 372.8
397.9	2,500.	335.4	—44°.07′	240.8	$-j$ 233.5
795.8	5,000.	237.4	—43°.13′	173.	$-j$ 162.6
1,591.6	10,000.	168.4	—41°.26′	126.3	$-j$ 111.4
15,916.	100,000.	67.12	—19°.19′	63.35	$-j$ 22.2

It will be seen in Fig. 6 that for low frequencies the initial sending-end impedance of an aerial line is only slightly greater than that of the particular cable-wire selected. At a frequency of 1,600 cycles per second, however, the impedance z_0 is much greater on the aerial wire than on the cable wire. This proposition has very general application. Again, wires of low resistance and leakance with respect to reactance tend to have a relatively small angle of impedance; while, on the contrary, wires of large resistance and small reactance tend to develop an angle of $-45°$ in their impedance z_0, especially at low frequencies.

The vector attenuation-constant a and the vector impedance z_0 completely define a line or conductor. If these two vectors are known for any given frequency, the constants of the line r, l, g and c are determinable. For by (10) and (16)

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$$a\,z_0 = r + jl\omega \qquad \text{ohms per mile or kilometre} \qquad (18)$$

or the product of these two vectors is the conductor impedance of the line per unit of length, from which r and l may be evaluated. Again

$$\frac{a}{z_0} = g + jc\omega \qquad \text{mhos per mile or kilometre} \qquad (19)$$

or the ratio of the two vectors is the dielectric admittance of

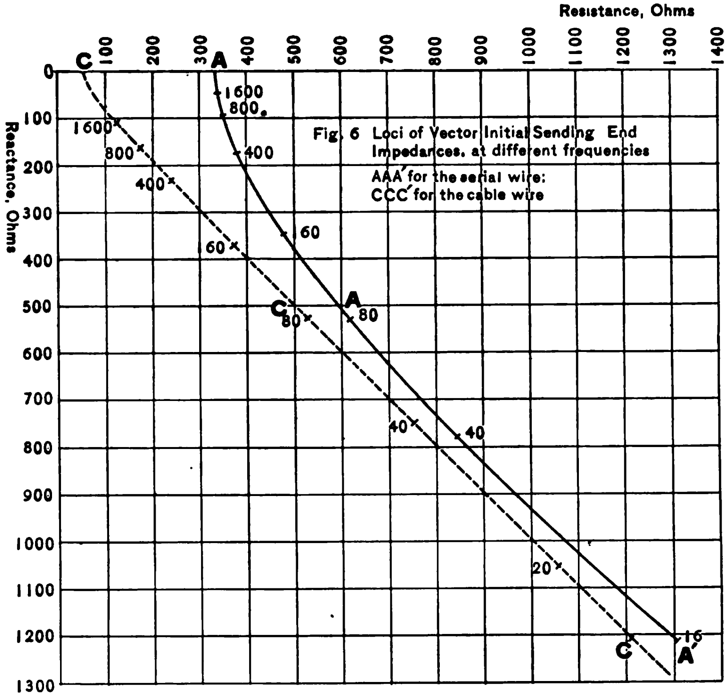

Fig. 6 Loci of Vector Initial Sending End Impedances, at different frequencies
AAA′ for the aerial wire:
CCC′ for the cable wire

the line per unit of length, from which the leakance g and capacity c may be found. Thus, Tables II and IV show that at the frequency of 796 cycles per second, ($\omega = 5000$) the attenuation constant of the cable wire is $0.118{,}0\ \underline{|\ 46^\circ.48'}$, per kilometre and the initial sending-end impedance is $237.4\ \overline{|\ 43^\circ.13'}$ ohms. The product of these is $28.0\ \underline{|\ 3^\circ.35'}$ ohms per kilometre $= 27.96 + j1.75$ ohms per kilometre, the linear impedance of the wire for this frequency; while the ratio of the vectors is

0.000,497 $\underline{|90^\circ}$ mho per kilometre, from which the capacity per wire mile is 0.099,4 microfarad per kilometre.

In a certain sense the characteristic vectors a and z_0 are more fundamental than the constants r, l, g and c as theoretically defining the electrical properties of a line, notwithstanding the fact that they vary with the frequency. For they are primordial in their control of those experimental phenomena from which the constants r, l, g and c are deduced.

Transmission Over an Indefinitely Long Line.

The alternating pressure and current along a line of uniform electric constants are subject to the following conditions:

$$e = \mathrm{E} \cosh \mathrm{L}_1 a - \mathrm{I} z_0 \sinh \mathrm{L}_1 a \qquad \text{volts} \qquad (20)$$

$$i = \mathrm{I} \cosh \mathrm{L}_1 a - \frac{\mathrm{E}}{z_0} \sinh \mathrm{L}_1 a \qquad \text{amperes} \qquad (21)$$

where e and i are respectively the voltage and current at the point considered distant L_1 miles (or kilometres) from the sending end; while E and I are the impressed voltage and the entering current at the sending end of the line. When the line is of such electrical length that the returning waves reflected from the distant end may be ignored, the steadily entering current I will be the same as the initial current $\frac{\mathrm{E}}{z_0}$. Consequently, for such long lines, we have

$$e = \mathrm{E}\,(\cosh \mathrm{L}_1 a - \sinh \mathrm{L}_1 a) = \mathrm{E}\,\epsilon^{-\mathrm{L}_1 a} \text{ volts} \qquad (22)$$

and
$$i = \frac{\mathrm{E}}{z_0}(\cosh \mathrm{L}_1 a - \sinh \mathrm{L}_1 a) = \frac{\mathrm{E}}{z_0}\,\epsilon^{-\mathrm{L}_1 a} \text{ amperes} \qquad (23)$$

Thus, the voltage and current along the line are simply the normally attenuating waves emitted from the sending end, the initial impressed voltage being E virtual, or r. m. s. volts, and this attenuates after running a distance L_1 miles (or kilometres) to E $\epsilon^{-\mathrm{L}_1 a}$ volts. Similarly, the initially outgoing current $\mathrm{I}_0 = \frac{\mathrm{E}}{z_0}$ virtual or r. m. s. amperes, attenuates to $\mathrm{I}_0\,\epsilon^{-\mathrm{L}_1 a}$ after running L_1 miles, that is it attenuates $\epsilon^{-\mathrm{L}a}$ in magnitude and is retarded $\epsilon^{-\mathrm{L}_1 a_2}$ radians in phase by (2). The product $\mathrm{L}_1 a$ may

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be called the *attenuation-length.* The coefficient ϵ^{-La_1} may be termed the *attenuation coefficient.*

As an example, we may consider a circuit length of 100 miles (160.9 kilometres) of the twisted pair cable of #19 A. W. G. copper wires already referred to, subjected to an impressed e. m. f. of 4 volts at a frequency of 796 cycles per second. This will correspond to 2 volts on each wire in the arrangement of Fig. 3. Table II gives the attenuation constant at $0.118 \underline{|\ 46°.48'} = 0.080,79 + j0.086,02$ per kilometre; while Table IV gives the initial sending-end impedance as $237.4 \overline{|\ 43°.13'}$ ohms. The initially outgoing current on each wire will therefore be $\dfrac{2}{237.4 \overline{|\ 43°.13'}} = 0.008,425 \underline{|\ 43°.13'}$ amperes; or 8.425 milliamperes leading the impressed e. m. f. by 43°.13', or nearly $\frac{1}{8}$th of a cycle. Because the cable is chosen so long, and the waves that return reflected from the distant end are so very minute, the outgoing current in the steady state has the same strength as the initially outgoing current. At a distance of $L_1 = 30$ miles say, (48.28 kilometres) the attenuation-length La_1 will be $48.28 \times 0.080,79 = 3.901$. The attenuation-coefficient will be $\epsilon^{-3.901} = \dfrac{1}{49.43} = 0.020,23$. The voltage will have fallen to $2 \times 0.020,23 = 0.040,46$ volt. The current strength will have fallen to $8.425 \underline{|\ 43°.13'} \times 0.020,23 = 0.170,4 \underline{|\ 43°.13'}$ milliamperes, the current still leading the local voltage by this phase. Both the current and pressure will, however, have been retarded in the transmission by $48.28 \times 0.086,02 = 4.153$ radians or 238°; so that the full expression of voltage and current for the point considered, with reference to the phase of the e. m. f. impressed at the sending end is

$$e = 0.040,46 \overline{|\ 238°} \quad \text{volt}$$

$$i = 0.170,4 \overline{|\ 194°.47'} \quad \text{milliampere}$$

The ratio of which is $237.4 \underline{|\ 43°.13'}$ ohms, or z_0.

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Table V gives the voltage and current in each wire of the circuit* for varying distances L_1 miles from the sending end.

Table V.

Attenuation-lengths and Attenuation-Coefficients for Cable Circuit at the frequency of 796 v or $\omega = 5{,}000$.

L_1		$L_1 a$ kilometric units		$\epsilon^{-L_1 a}$		e	i
miles	kilometres	$L_1 a_1$	$L_1 a_2$	attenuation coefficient	lag	volts	milliamperes
0	0.	0.	0.	1.0	0°.	2.0	8.425 | 43°.13′
1	1.609	0.13	0.138,4	0.878,1	7°.55′	1.756,2 | 7°.55′	7.398 | 35°.18′
2	3.219	0.26	0.276,9	0.771,1	15°.50′	1.542 | 15° 50′	6.498 | 27.°23′
5	8.046	0.65	0.692,2	0.522,1	39°.40′	1.044 | 39°.40′	4.399 | 3°.33′
10	16.09	1.30	1.384	0.272,5	79°.20′	0.545 | 79°.20′	2.296 | 36° 7′
20	32.19	2.60	2.769	0.074,31	158°.40′	0.149 | 158°.40′	0 626 | 115°.27′
30	48.28	3.90	4.153	0.020,23	238°.0′	0.040,5 | 238°	0.170 | 194°.47′
50	80.46	6.50	6 922	0.001,503	396°.36′	0.003 | 396°.36′	0.013 | 353°.23′

* Compare Curve 1, Fig. 1, Dr. H. V. Hayes "Loaded Telephone Lines in Practice" Trans. International Electrical Congress, St. Louis, 1904. Vol. III, p. 643.

(To be continued.)

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Editorial.

It gives us great pleasure to announce that Prof. L. S. Marks has been elected auditor of the JOURNAL and that Mr. G. A. McKay, '08, of Danbury, Conn., has been elected a member of the Board of Editors.

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Below we present the names of the officers of the various Scientific Societies and Clubs associated with the Division of Engineering.

These Clubs are in general open to all students who may be interested. They all have the common purpose of promoting the discussion of Engineering subjects together with a pleasant social intercourse of members.

Men wishing to join these organizations should communicate with the officers below.

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Treasurer, J. B. Lewis, Jr. '06, 20 Stoughton Hall.

The seventh annual dinner of the Harvard Engineering Society was held on May 19, 1905, at the Hotel Westminster, Boston. Prof. Kennelly was chairman. The speakers were Prof. Wyman, Mr. Stickney of Cornell, Mr. Moyer, Mr. Ross, Mr. Newell, Mr. Durfee, Mr. Furness, Prof. Hollis.

The first regular meeting of the Engineering Society this year was held on Monday evening, Oct. 30, in Pierce Hall. Mr. C. J. H. Woodbury of the American Bell Telephone Co. delivered a lecture on "Telephone Line Engineering" illustrated by lantern slides.

The first meeting of the Harvard Electrical Club this year, was held on Thursday evening, October 19, in Pierce Hall. Many old and new members of the Club were present. There were informal talks by Prof. Kennelly and Prof. Adams.

The Harvard Mining Club held its first meeting in the Harvard Union on Friday, Oct. 20. The meeting was addressed by Prof. H. L. Smyth.

The Harvard Mechanical Club met on November 15. Mr. H. E. Duncan of the American Waltham Watch Co., gave a description of the "Mechanism of the Pocket Watch." On the next two days, November 16 and 17, the members of the Mechanical Club visited the works of the Watch Company in Waltham.

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Notes.

Prof. I. N. Hollis is now in Geneva, Switzerland, with his family. He is expected to return for the second half year.

Prof. F. L. Kennedy is on leave of absence for a year. He will spend his time in studying the draughting-room methods of various manufacturing establishments. He is now with the General Electric Co. in Lynn, Mass. His address is 202 Ocean St., Lynn.

E. B. Whitney and W. V. Moses are also working in the draughting room of the General Electric Co.

After a year of absence Prof. C. A. Adams has returned to Harvard, to resume his work in the Electrical Department.

Mr. C. O. Mailloux who has recently written for the JOURNAL on "Train Resistance," is giving a course of lectures in the Brooklyn Polytechnic Institute. His lectures will cover the subject of "Electric Train Movement."

J. J. Eaton, '96, is Superintendent of the Philippine School of Arts and Trades at Manilla, P. I.

H. W. Howe, '97, and F. H. Eichorn, '01, are working in Boston in connection with the Charles River Dam.

E. W. Stevens, '99, is in Boston with a firm of bankers and brokers.

Granville Johnson, '03, of the 1902 JOURNAL Board is Assistant Chief Engineer of the Union Electric Light and Power Co., St. Louis, Mo.

Kenneth Sherburne, '03, is in the draughting room of the Sturtevant Blower Co.

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E. J. Whittier, '01, is in the purchasing agent's department of the Agricultural Chemical Co. He is stationed in New York.

H. M. Hale, '04, is Assistant Engineer of the Board of Rapid Transit, R. R. Commrs. His address is 231 W. 125th St., New York, N. Y.

Louis Ross, '04, is on the U. S. Geological Survey (Hydrographic Branch) Washington, D. C. During the summer he was in charge of a party which surveyed some hundred miles of the Roanoke River in Virginia. At present, he is in Washington working up results for publication. Address,—Care U. S. Geological Survey, Washington, D. C.

A. Locke, '04, and Guy Stoltz, '05, have gone into partnership as mining Engineers in Salt Lake City, Utah.

P. A. Marean, '05, is at Purdue University acting as research assistant to Prof. Goss in locomotive testing.

Aldrich Durant, '03, is in Cambridge assisting Prof. Marks in the Mechanical Engineering Courses of the Senior year.

H. W. Sturgis, '05, is working under Prof. Adams on motor driven sugar drying machinery at the works of the American Tool & Machine Co., Brooklyn.

W. M. Gould, '05, is engaged in telephone work for the American Telephone and Telegraph Co.

W. Lewis, '05, is learning Cotton Machinery with the Draper Co., Hopedale, Mass.

The following men are reported from Schenectady working for the General Electric Company. C. J. Cutting '05, F. P. Coffin '04, D. Dubois '03, F. H. Poor '04, H. D. Kernan '05, H. Morgan '06, E. N. Willis '03, A. H. Train '05, D. L. Furness '05, W. O. Batchelder '05.

J. R. Lewis, '05, and Bryant White, '05, are working for the Bullock Electric Manufacturing Co., in Cincinnati.

E. C. Stone, '04, F. W. Cloud, '05, P. M. Patterson, '05, are in Pittsburg with the Westinghouse Electric and Mfg. Co.

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S. F. Rockwell, '00, is with Davis & Furber Machine Co., Andover, Mass.

A. L. Haskell, '03, is superintendent of construction work for the National Underground Cable Co., Pittsburgh.

Architectural Notes.

L. P. Burnham, '02A, holder of the Nelson Robinson Jr. Travelling Fellowship in Architecture for 1903–04, and of the Julia Amory Appleton Fellowship for 1904–05, has settled down in Paris to work for another winter.

A. H. Blevins, '98A, of the firm of Newhall and Blevins is one of the architects of a large new apartment house erected during the past summer on Brattle Street, Cambridge.

C. H. Ely, Sp. '98, who is in independent practise in Beverly, Mass., was the architect for a new building recently erected for Dummer Academy near Newburyport, Mass.

C. F. Gould, '98, spent the summer in San Francisco, working under the direction of D. H. Burnham *h*'93, of Chicago, the architect who has been so largely concerned in the recent work of the architectural development of Washington and Cleveland. Mr. Burnham has now prepared plans for future development of San Francisco, which on account of its exceptional situation bids fair to be one of the most beautiful cities in the country, if not in the world.

T. M. Hastings, '98A, until recently in independent practise in Philadelphia is at present the junior partner in the firm of Brockie and Hastings in that city.

A. E. Hoyle, '04A, has been appointed Assistant in Architecture in Harvard University.

J. L. Peabody, '03, and H. S. Cobb, Jr., '04, are working at the Ecole des Beaux Arts in Paris.

C. R. Wait, '03A, holder of the Nelson Robinson Travelling Fellowship in Architecture for 1904–05 has recently returned to this country.

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W. L. Mowll, '99A, has been appointed Assistant Professor in Architecture at Harvard University.

W. E. C. Nazro, '98A, is welfare agent for the Plymouth Cordage Company at Plymouth, Mass. In that capacity and as the Company's architect he is concerned with the housing, general comfort and recreation of its employés. He has recently been employed by the United States Government to study the welfare of the workmen employed upon the Panama Canal.

Exchanges.

The Journal wishes to acknowledge the following Exchanges: The Iowa Engineer, Journal of the Association of Engineering Societies, Stevens Institute Indicator, Journal of the Franklin Institute, Engineering Press Index, Engineering Index, Harvard Graduates' Magazine, The Wisconsin Engineer, Journal of the Western Society of Engineers, The Technical World, Technology Review, The Technograph, The Sibley Journal of Engineering, The Polytechnic, The Michigan Technique, Electrical Club Journal, Proceedings of the American Society of Mechanical Engineers, Proceedings of the American Institute of Electrical Engineers, Proceedings of the American Society of Civil Engineers, Journal of Worcester Polytechnic Institute.

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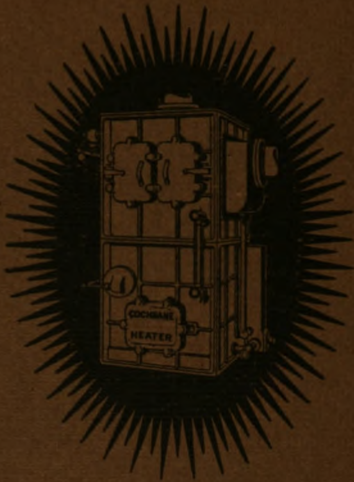

COCHRANE HEATERS

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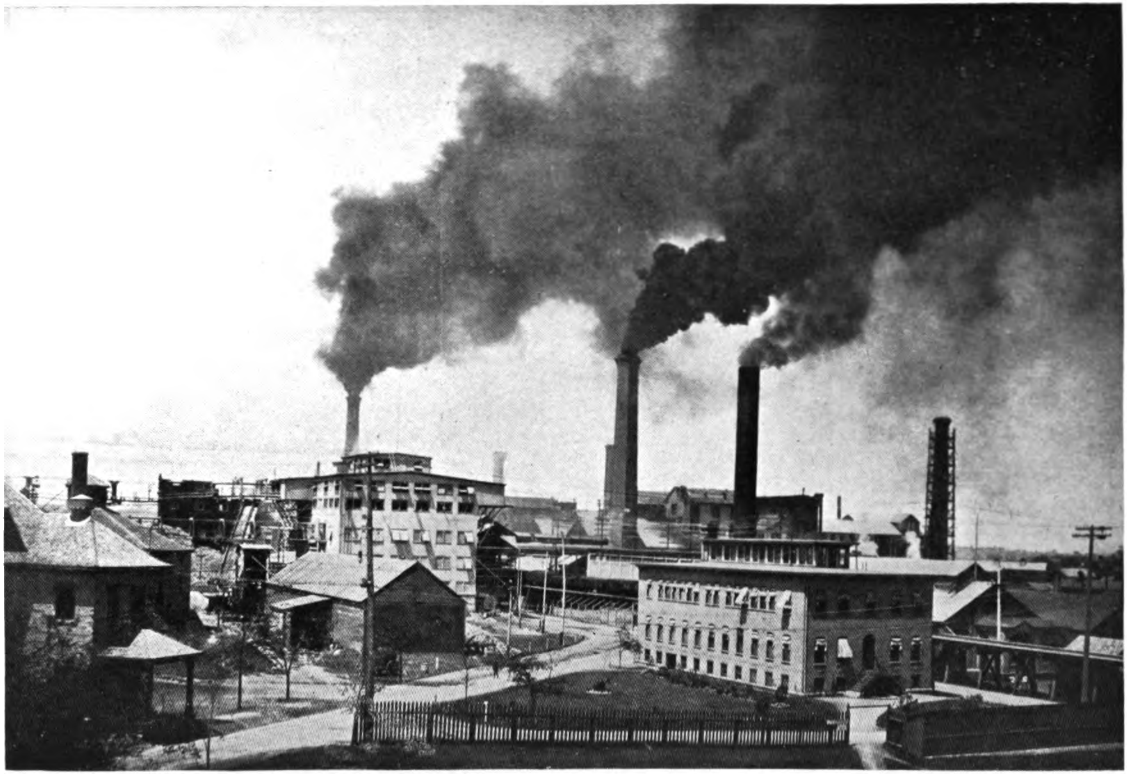

Fig. 5.
Comparison of the Smoke from Hand Fired and Machine Fired Furnaces.

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SMOKE PREVENTION AND ECONOMICAL COMBUSTION.

By Lionel S. Marks.

Assistant Professor of Mechanical Engineering.

The prevention of smoke is a subject which has aroused attention wherever bituminous coal or other gas-producing fuel has been burned in large quantities. Previous to the last century such fuels were used mainly in private houses and the smoke nuisance was relatively inconsiderable, but with the rapid increase in the use of the steam engine and the general stimulus to metallurgical processes which resulted therefrom the emission of smoke began to be a serious nuisance and has continued to be so to the present day. During the past century numerous scientists and inventors have been actively engaged in endeavoring to overcome or diminish the nuisance. Ordinances have been passed in all the large industrial centres of the western peoples forbidding the emission of smoke under certain penalties, valuable prizes have been offered for satisfactory smoke-preventing devices, and a large reward has been certain to the successful inventor. Under this stimulus the patent offices have been overwhelmed with smoke-preventing or smoke-consuming inventions; Select Committees on Smoke Consumption have been appointed by the British Parliament and after hearing hundreds of opinions have published voluminous reports showing just how to combat the nuisance; special exhibitions of smoke abating contrivances have been held at South Kensington, Manchester, and elsewhere, with complete tests made of the contrivances and full reports issued; special organizations of manu-

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facturers have been formed in many places for the special purpose of combating the evil, and they have planned, carried out and reported on elaborate special investigations throwing valuable light on the subject. But in spite of all these efforts, individual, organized and official, in spite of more than a century of ceaseless and intelligent endeavour the smoke nuisance remains; not, it is true, as grave a nuisance as it would have been without these numberless investigations and inventions but grave enough to be still destructive to the beauty and cleanliness of many of our cities, a source of considerable expense to the individuals living in those cities, and, indirectly, a menace to the health and happiness of millions of people.

And yet, the problem is simple; so simple that it can be made clear to the least intelligent of firemen. All that is necessary is that the fuel should be completely burned; and to effect this it must be brought into intimate contact with a sufficient amount of air while it is at a sufficiently high temperature. With complete combustion of any of the ordinary fuels the products of combustion are practically colorless; with a fuel like anthracite or coke, the combustible parts of which consist practically of pure carbon, there will be no smoke even if the combustion is incomplete since the only possible products of combustion are carbon dioxide and carbon monoxide, both of which are colorless gases; but with fuels such as bituminous coal or oil, which consist in part or entirely of hydrocarbons, incomplete combustion results in the splitting up of the hydrocarbons and the liberating of carbon particles so that the products of combustion carry with them solid particles of carbon or soot and become visible as smoke.

The conditions under which smoke forms can be very readily seen by experiment with an ordinary oil lamp. When properly adjusted the combustion is perfect, the products of combustion arising from the flame are colorless and there is no deposit of soot. If the wick is turned up the lamp begins to smoke because the air supply is now insufficient for the increased amount of oil being burned. If the chimney is raised slightly there is again smoke but now it is because the air supply becomes excessive, chilling the flame to too low a temperature. If a cold metal rod is inserted in

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the chimney, soot will deposit on it, again as a result of the chilling of the flame. The requisites for complete combustion are sufficient air (but not too much), a sustained high temperature and a thorough mixing of the gases.

But although the conditions requisite for perfect combustion can be readily stated they cannot be as readily obtained in the ordinary boiler furnace. The ordinary furnace is of considerable extent, has on it coal in all stages of combustion, in a bed of varying thickness, and the conditions at each part of the grate are varying continually. To ensure that the burning fuel at each part of the grate shall get sufficient air for its complete combustion, that the gases distilling out of the coal shall always be thoroughly mixed with the air and that the gases shall not be chilled to too low a temperature before combustion is complete, is a problem the solution of which offers considerable practical difficulties. The general requisites are the same in every case but the methods of satisfying them differ with the construction and conditions of operation of each furnace.

A sufficient air supply can be ensured by having a considerable excess; for example, if the air supply in the ordinary hand-fired furnace is made so ample as to burn the gases distilled out when fresh coal is thrown on the fire, it will be sufficient at all times. Such an air supply will be much more than sufficient during the greater part of the time of operation but if it is not in such large excess as to cool the gases below the ignition temperature and thereby to prevent complete combustion, no smoke will be formed if the other conditions are satisfactory. This method of smoke prevention, however, though satisfactory to the general public is by no means satisfactory to the manufacturer. The large excess of air carries a large amount of heat up the chimney, and causes a low efficiency of the boiler plant and an increase in the amount of fuel burned. A certain excess of air over that actually used up by the combustion is always found to be necessary in order to ensure that every part of the combustible meets the oxygen with which it is to combine; any air in excess of the necessary excess is a source of loss since that air does no good and escapes at the chimney at a high temperature, carrying off heat which otherwise

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might have been given to the boiler. Under ordinary boiler conditions the excess of air necessary for complete combustion is from 80 to 100% of that used up by the combustion. If the excess of air is less than that amount there may be more or less incomplete combustion and consequent smoke production — if it exceeds that amount there may be complete combustion but there will be a decrease in efficiency. The production of smoke with the smaller excess of air is plain evidence of a decreased economy from incomplete combustion but the disappearance of smoke with the larger excess may mean a still greater loss of efficiency.

Some recent careful tests in Germany throw light on this point. A certain boiler was tested under different conditions of air supply and from the observations there was calculated the heat balance, that is, the distribution of the heat of perfect combustion of the coal. The heat balance is in four parts: (1) the heat actually going into the boiler to form steam, (2) the heat of combustion of such coal as fell through the grate unconsumed or partly consumed, (3) the heat carried away by the chimney gases and (4) the heat lost in other ways, that is, by conduction and radiation from the boiler, by incomplete combustion of the gases, and in other minor ways.

The heat lost by radiation and conduction from the boiler and in other minor ways is practically constant so that any variation in the quantity (4) can be considered as due to a variation in the amount of the gases escaping incompletely burned. The results of the tests are given in the following table.

	Test A	Test B	Test C	Test D
Excess of Air	Very Small	Moderate	93%	177%
Appearance of Chimney Gases	Dense Smoke	Medium Smoke	Practically Smokeless	Slight Smoke
Heat Balance				
(1) Heat utilized for making steam ..	54.4%	63.5%	69.2%	61.0%
(2) Heat lost by unburned coal	2.4%	3.5%	2.8%	3.9%
(3) Heat lost up chimney...........	17.6%	15.4%	17.8%	28.6%
(4) Heat lost by radiation, conduction, unconsumed gases, etc.	25.6%	17.6%	10.2%	6.5%

The table shows very clearly the increase in the chimney loss with increased excess of air and the decrease in the loss from in-

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complete combustion of the gases at the same time. Test C with 93 per cent. excess of air shows the most economical running, with a boiler efficiency of 69.2 per cent. and practically no smoke. With the larger excess of air (test D) the increase in the chimney loss more than offsets the decrease in the loss from unburned gases so that the total efficiency is decreased. That the absence of smoke is not an evidence of more economical running is shown by a comparison of tests B and D; the loss by less complete combustion of the earlier test is more than offset by the greatly increased chimney loss of the later test. These tests show that the conditions of smokeless operation for the boiler under test were also the conditions of greatest efficiency, but they are not necessarily so for other boilers. It happens in many boiler plants that the simplest method of obtaining smokeless combustion is by the admission of an excess of air so large as to reduce appreciably the efficiency of the plant. Consequently there is often in the ordinary plant a conflict of the public interest and of the interest of the manufacturer. The continuation of the smoke nuisance is in large part due to this conflict. The conflicting interests can, however, be reconciled by the adoption of special methods or devices for bringing about complete combustion with a moderate excess of air.

In any particular plant the appearance of smoke may be due to many different causes and a special investigation is necessary in any case in order to discover the cause of the trouble. Before a complete investigation can be carried out it is necessary to have some method of defining and recording the amount of the smoke. There is no method at present known for making exact smoke measurements but comparative measurements can be made either quantitatively or qualitatively.

The simplest of the quantitative methods is to insert a cold metal plate in the path of the gases for a definite time and then to brush off and weigh the soot which has accumulated on it. This method is not continuous and is generally unsatisfactory.

The qualitative methods are all based upon the appearance of the smoke. They are open to the objection that the appearance of the smoke depends on its volume, on the velocity of the wind, on the kind of background against which it is seen (whether clear

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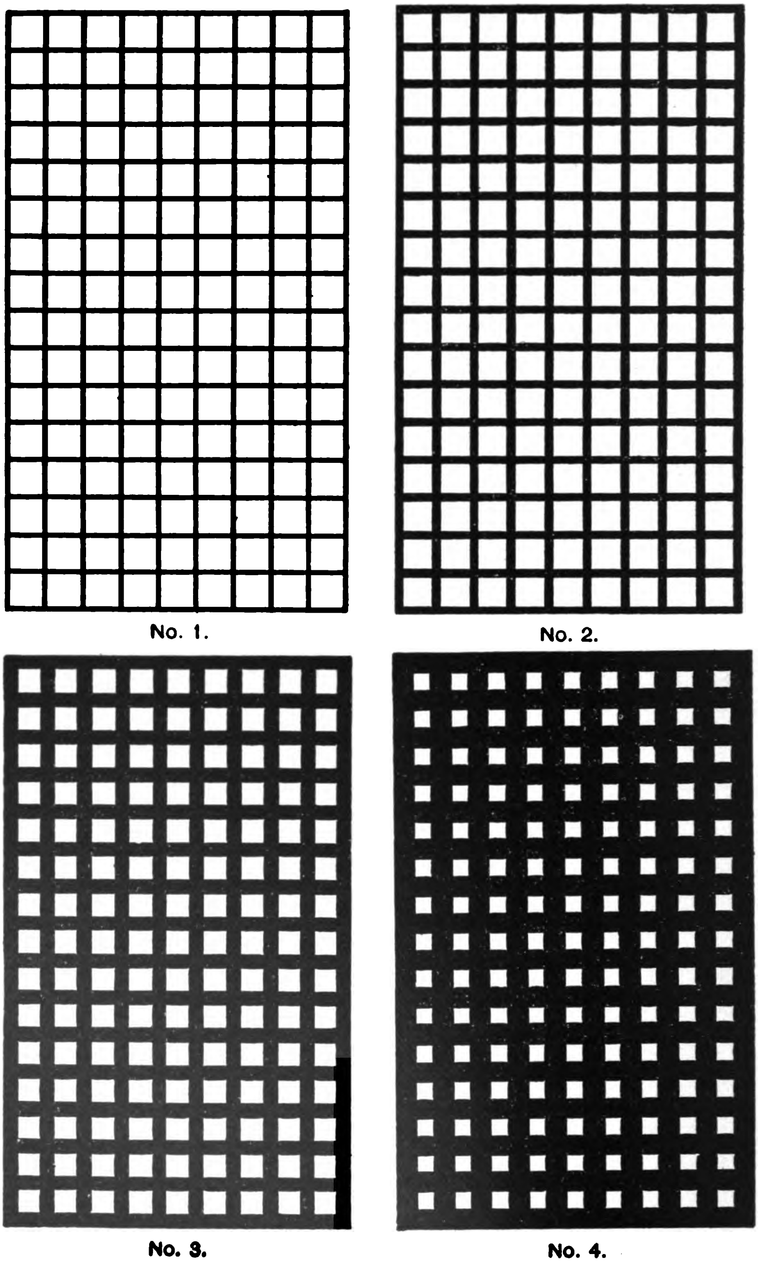

Fig. 1.

sky or clouds) and on the judgment of the observer. As a method of comparing the smoke from day to day it is very unsatisfactory since what would appear as light smoke on a clear day with a strong wind might seem quite heavy on an overcast calm day. In observing the variation of the smoke from minute to minute with the object of determining the cause of the smoke the qualitative method can be used quite satisfactorily.

A number of different scales have been suggested and used for stating the appearance of the smoke. The best of them is that proposed by Prof. Ringelmann of Paris, which is illustrated in fig. 1. In making smoke observations, a white card, four large cards ruled exactly like those in the figure, and a card in solid black are placed side by side at a distance of about 50 feet from the observer and between him and the chimney. The cards are numbered from 0 for the white to 5 for the black card. The ruled cards appear gray of different densities and the smoke can be compared directly with them for density. If the smoke is variable and a continuous record of its density is made for a number of hours it is generally possible to account for the smoke by keeping close account of every operation in the fire-room and of the exact time at which it took place.

An example of the method, taken from a recent test by the writer, is shown in fig. 3. The plant had five boilers in operation at the time of the test. The record is for a period of 75 minutes and shows on the upper curves the density of the smoke according to Ringelmann's scale, on the lower curves the amount of the opening of the damper, and below the lower curves it shows by various symbols the times of various operations on each of the five boilers. The draft was controlled by an automatic damper regulator actuating the main damper at the base of the chimney. The boilers had automatic stokers of the step-grate type.

An examination of the record brings out quite clearly the cause of the smoke. Each time the damper closed, or nearly closed, the smoke increased. This result is quite natural. The damper when closed cut the draft down so much that the air supply became insufficient to burn the gases which were being given off continuously and incomplete combustion resulted. The smoke arising

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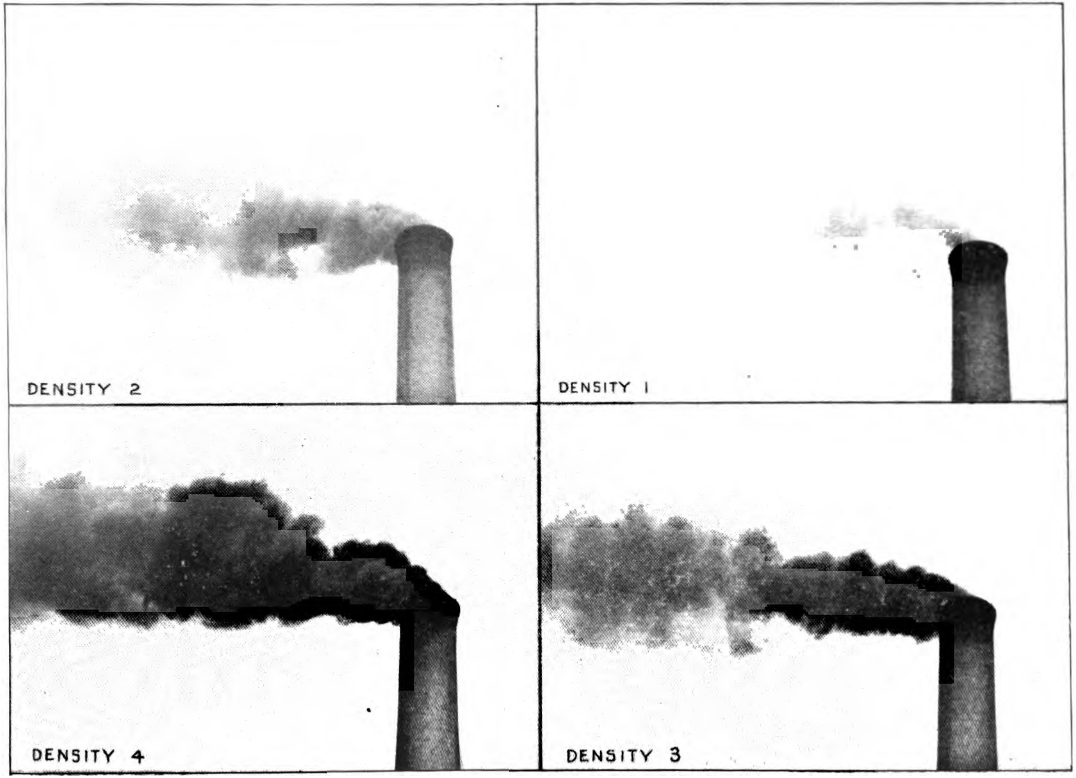

FIG. 2.

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from this cause was done away with by resetting the damper so that even when closed to the limit of its movement there still remained a considerable opening and consequently sufficient draft to burn the gases. With a heavier load the damper would not have closed so often and the smoke from that cause would then be less. The load was liable to increase at any moment up to the full power of the five boilers so that all had to be operated.

A further inspection of the record shows one other factor to be important in that case in producing smoke, namely the operation represented by the rectangle □. It will be seen that, although it was not invariably true, it was generally the case that when the operation represented by the symbol □ took place there was an increase, often a sudden increase, in the density of the smoke. The grates were not kept entirely covered by the mechanical stokers and became bare at the sides if untouched. If this were permitted a large excess of cold air would enter at the sides, reducing the efficiency of the boiler; to prevent this loss the firemen poked coal into the sides of the grate at frequent intervals. The symbol □ shows when this poking occurred at each boiler. Its effect was to push green coal suddenly into the furnace and into contact with incandescent fuel. The hydrocarbons were then given off rapidly in large volume, and escaped incompletely burned. If only a little coal was poked down no noticeable increase of smoke took place; if several furnaces were being poked at about the same time the smoke became very dense. To overcome this trouble various structural changes had to be made in the furnace so that the grates could keep themselves covered over their whole surface.

If the smoke remains continuously of considerable density the method of investigation outlined above will be of little service. In that case it is obvious that some one or more of the general conditions of operation is unsatisfactory. Analyses of the flue gases will show whether the trouble arises from too little draft. If the carbon dioxide in the flue gases exceeds 13 or 14 per cent. the smoke will probably be due to deficient air supply — if the amount falls below 10 per cent. the supply of air is excessive and the loss of heat up the chimney will be considerable. With the carbon di-

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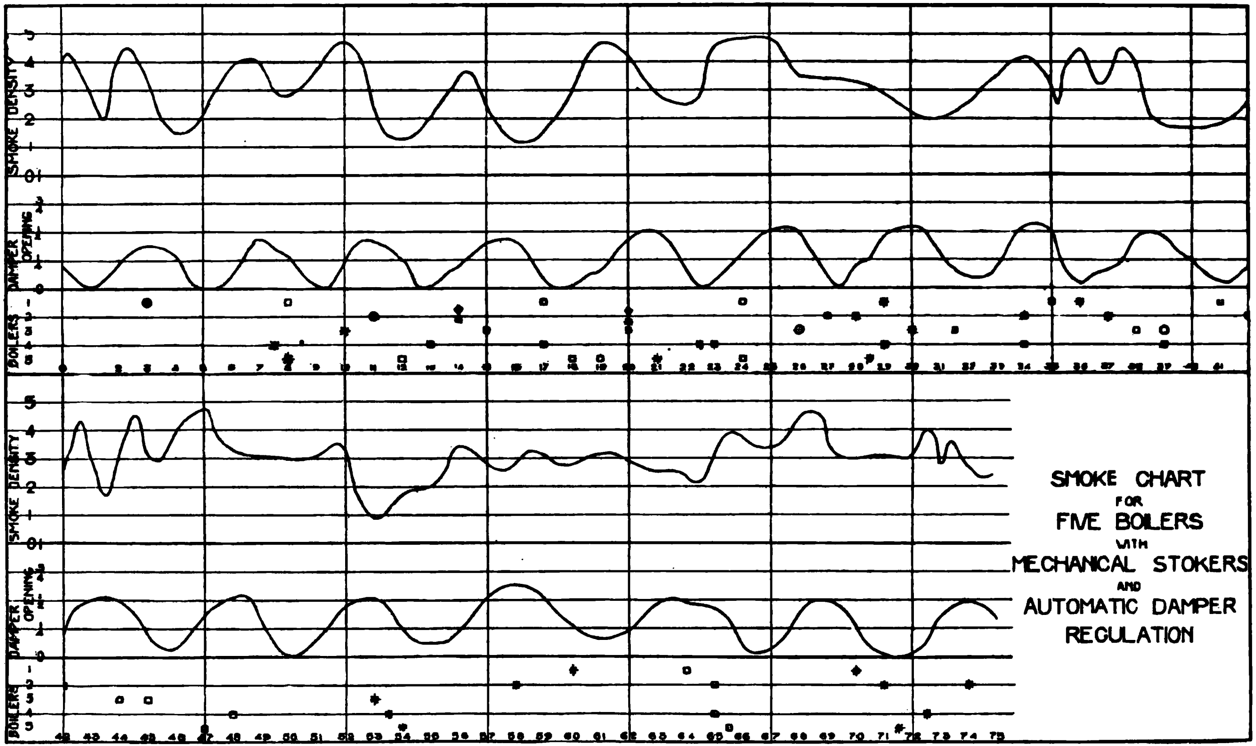

FIG. 3.

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oxide ranging between 10 and 13 per cent. it should be possible to combine high efficiency with smokeless operation. Another condition which may cause continuous smoke is the too close proximity of the heating surface to the fire. If the flames strike the heating surface the burning gases may be cooled by the contact to a temperature too low to permit of the continuation of the combustion. The remedies for this are either the use of less gaseous fuel or a rebuilding of the furnace.

For combustion to be both smokeless and economical, when occurring in a properly designed furnace, it is necessary, either that there should be a continuous adjustment of the air supply to the

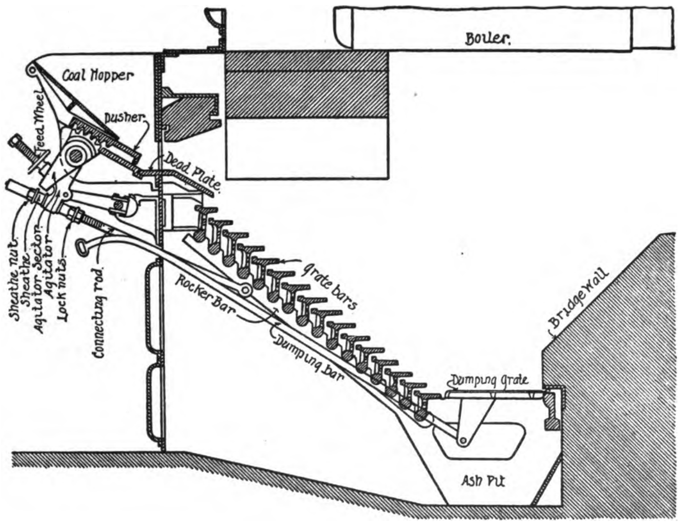

FIG. 4.

varying demand, or that the conditions in the furnace should be kept constant so that the demand for air is constant.

In a hand fired furnace where the conditions are necessarily variable the first step towards smokeless combustion is to reduce the variation as far as possible. This is best accomplished by thoroughly coking the coal on the dead plate before scattering it over the fire, or, if the boiler is being forced, by heaping the green coal on the front end of the grate and pushing it back after most

of the volatile matter has been distilled out of it. With either process a certain amount of air, preferably hot air, has to be admitted on top of the fire, in such manner as to mix well with the gases, if smoke is to be avoided. The air admitted in this way should be considerable in amount immediately after firing, but the supply should not last more than two or three minutes as the gases come off rapidly for a short time only. To supply this air the fireman may leave the fire door slightly open or may open a grid in the fire door, or else various mechanical devices, operated by the opening of the fire door, may be used. One of the common devices

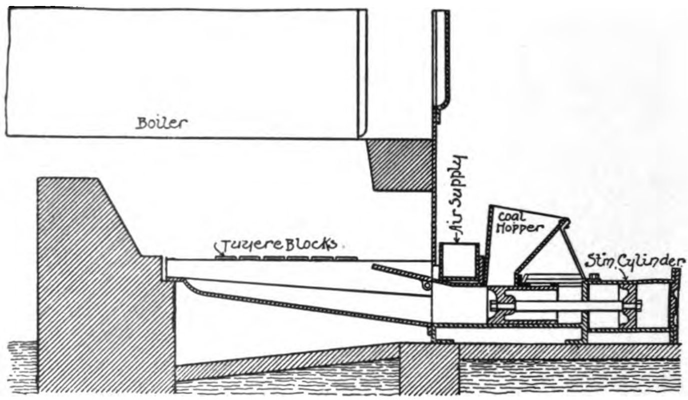

FIG. 6.

is a steam jet blowing air on top of the grate and having some dash pot or other mechanism for controlling the duration of the blow. A similar result is sometimes obtained by increasing the damper opening for a desired interval of time by means of a similar mechanism. Such adjustments of the air supply when carried out intelligently can be extremely effective in preventing smoke but in the hands of the ordinary fireman may be not only ineffectual but also a source of loss of economy.

The better method is to keep the conditions in the furnace constant; this is what the mechanical stokers aim to accomplish. In the normal operation of a satisfactory mechanical stoker and with a constant demand for steam, the coal passes through the fur-

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nace in a continuous stream entering as green coal, leaving as ash. The condition of any part of the grate remains unchanged (except in some forms, for the accumulation of clinker) from hour to hour so that the same amount of air is required all the time. Under these circumstances it is possible to control the air supply to give both smokelessness and high efficiency.

Of the various types of mechanical stokers in common use some have special advantages as smoke-preventers. With stokers of the inclined grate type (fig. 4) there is often more or less trouble in keeping the grate uniformly covered with fuel. The coal is coked at the top of the grate by heat from a refractory arch, and

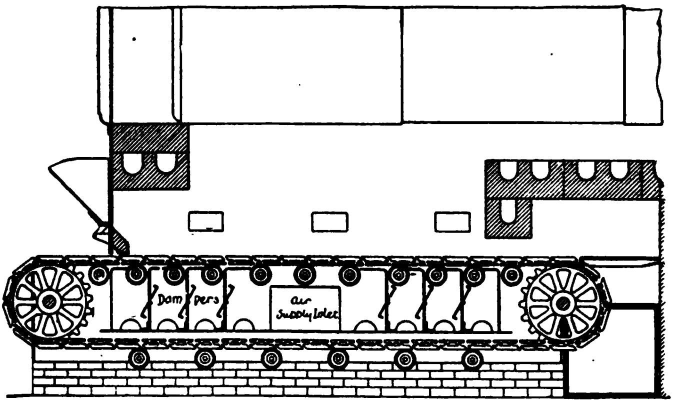

FIG. 7.

a stream of heated air drawn in by steam jets or by the chimney draft is directed onto the gases. With careful adjustment practically smokeless combustion can be obtained but under ordinary circumstances such furnaces are seldom smokeless though showing a considerable improvement over the hand-fired furnace. A good illustration of the effect of the installation of mechanical stokers of this type is given in fig. 5, which shows the smoke from three boiler plants all of the same type and of about the same power. The dense smoke from the two brick chimneys is from hand-fired plants, the lighter smoke from the steel chimney is from a plant with mechanical stokers.

The underfeed type of mechanical stoker (fig. 6) is generally a good smoke preventer and may be very economical even with a comparatively small excess of air. The passage of the gases mixed with air through the incandescent fuel on top ensures a most thorough mixture of the gas and the air, and a very high temperature of the mixture — so that unless the air supply is deficient this type of stoker is practically smokeless. The down-draft furnace has a similar action and though hand fired it can be operated with very little smoke.

The chain grate type of stoker (fig. 7) is admirable as a smoke

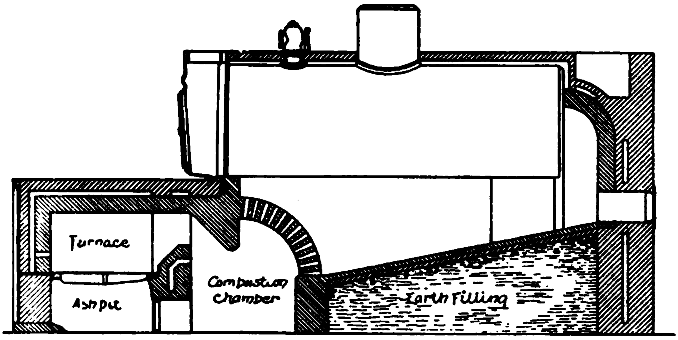

FIG. 8.

preventer but it may be extremely uneconomical if not operated with considerable intelligence. The gradual approach of the green coal to the hotter part of the furnace causes a very slow distillation of the gases. The grate is self cleaning so that one of the common causes of occasional smoke is entirely removed. Without constant intelligent adjustment of the rate of travel of the grate and of the thickness of the fire the grate may become bare at the rear admitting a large excess of cold air or else considerable partly burned coal may be dumped into the ash pit.

With either hand firing or mechanical stoking it is necessary for smokeless combustion that the flames should not come in contact with any cool surface before combustion is complete. A good way of ensuring this is to have the fire in an outside furnace away from the boiler (fig. 8) and to cause the burning gases to pass through

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contracted passages, lined with refractory material, before they reach the boiler heating surface. In this way a very high furnace temperature is obtained and also a thorough admixture of the air and gases. It should be possible with such a furnace not only practically to ensure smokelessness but also to obtain a higher efficiency than with the other devices described. The provision for mixing can be made so adequate that only a small excess of air need be used — the most important condition for high efficiency.

Whatever device may be used, the smokeless economical operation of a steam plant can only be obtained by intelligent adjustment and oversight. With a plant running under a constant moderate load the problem offers no important difficulties; — with large variation of load or a heavy overload the difficulties are much greater. But these difficulties are not insuperable, and although there will always be smoke so long as soft coal is burned there is no reason why its amount should not be decreased continuously in response to a quickening public demand for its abolition.

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TELEPHONE LINE ENGINEERING.

By C. J. H. Woodbury, Boston, Mass.,
Assistant Engineer American Telephone and Telegraph Company.

[Read before The Harvard Engineering Society, October 30, 1905.]

The wonders of the telephone as the most subtle of physical apparatus, yet so simple as to be the only electric device operated without skill, an invention without precedent which has also escaped improvement, has worthily been the theme of frequent portrayal, which has also been devoted to that concentration of applied science upon the switchboard and the transmitter, each of them essential adjuncts in the development of the telephone system.

The salient characteristic which justifies all commercial applications of electricity, except those of industrial chemistry, is that it overcomes the impediment of distance, and it is essential that the conductors spanning these long extents, free from direct supervision, shall be as permanent as possible in order to maintain conditions of constant service.

The amount of capital amassed in the approximately 4,500,000 miles of line construction necessary to connect together in a unity the subscribers of the Bell telephone system is of itself a warranty as to the importance of the subject; while the rapid depreciation to which most of this property is subjected requires both technical skill and business judgment to decide upon the most judicious methods of construction of this vast plant, amid varying circumstances of natural conditions and commercial use, in order to reach the most economical point of investment.

Analyze the general problem as one may, and standardize the general methods to cover a wide range of circumstances, yet there are exigencies and varying conditions which require the

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exercise of that type of constructive engineering which "does things."

"The picture is first rate, but we built the bridge last night," said the Maine lumberman in the army to his West Point commander.

The application of mathematical principles is essential to any constructive work which is not merely a repetition of precedents, and the ordinary precedents of safe construction have been established upon the wrecks of past failures perhaps for generations agone.

In this paper it is proposed to submit some of the difficulties which have been met in line construction and the manner in which these obstacles have been overcome, as well as ordinary methods of standard construction.

The increase of every commercial application of electricity to meet the demands to supply service to patrons has been so great that an essential portion of every problem in constructive electricity must take into consideration provisions for future growth as well as the inevitable depreciation.

Poles.

Although forty-five per cent. of the wires are on poles, the total extent of the pole lines exceeds the length of the underground conduits, as the latter are used only in cities where the conduits contain a greater number of lines to reach the concentration of patronage.

The extent of the pole lines is shown by the fact that in the Bell telephone system there are approximately 6,800,000 poles, and about 1,000,000 are required annually for replacement and for extension of lines.

A number of years ago a large collection of logs, known as the Joggins raft, was towed from Nova Scotia to New York, and this raft contained many long poles which were not suitable for masts.

Some of these long poles were used for the largest pole line ever built, at the westerly side of New York City, and carrying

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250 wires each. At the present time there are single underground cables comprised of $4\frac{8}{10}$ times as many conductors, and under the main streets in the principal cities are conduits of sufficient capacity to carry four hundred times as many wires as one of these pole lines

The typical methods of setting poles will first be described.

Where the soil is not firm enough to sustain a pole imbedded in the usual manner, security may be obtained by extending the supporting area by plank at the bottom of the excavation and filling the hole with concrete, of braces may rest upon a platform placed on the surface of the ground, and in some instances these platforms rest upon piles.

In other instances these braces rest upon plank placed underground, or, in place of a single pole, they are placed in pairs, either vertical or joined at the top and connected by strong wire at the ground, making what is known as an A pole.

When the line changes its direction or there are other causes to make a lateral pressure against a pole, it is secured by braces or by guys, either running to an anchorage in the earth or to some other object.

When a telephone line is built in or near cities, the close connection with supplies and labor renders that portion of the work comparatively easy, but in the construction of long distance lines across country, connecting various cities, town and villages within speaking distance of each other, it is necessary to provide means for the execution of the work on an independent basis.

In a suitable locality, a camp consisting of a number of tents is pitched, one of them being a dining tent, another is where the cook holds sway, and the engineers' tent, where such details as must be left until the work is in progress receive attention, while several tents are necessary to provide for the sound sleep which awaits the close of a good day's work.

If the route runs through a wooded country, a wide swath is cut in the forest and the post holes may be made by the diggers, or in other instances a charge of dynamite deposited in an auger hole makes quick work, the greatest relative gain being in compact clayey soil.

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Meantime the poles have been brought to their sites by teams and then moved to the exact place by the help of an axle mounted on a pair of wheels termed a dinkey; gains are cut and the cross-arms attached before they are raised, either by all hands with pikes giving a long push, a strong push and a hard push altogether, to change the old aphorism, or if the country is not too rough to permit, a portable derrick mounted on a wagon is drawn to the site, then the horses are detached from the wagon and pulling at the rope quickly raise the pole.

Then the derrick wagon is drawn to the next pole and the work proceeds rapidly.

When the line changes in direction, the pole is rendered more secure by guys and the pole line is ready for the wires which are payed out from a number of reels in a wagon, thence passing through a set of guiding holes which prevent snarling.

The final attachment of the wires to the insulators on the cross-arms is very carefully done, because it is necessary that the wires should be drawn to an extent that they should not sway against each other, and yet not so tightly that the contraction in cold weather would put a stress on the wire which would produce danger of breakage, for at these small amounts of dip in the wires a slight difference in the length of the line will cause a great variation in the stress.

The stresses to which a telephone pole is subject are the result of many and variable combinations of live and dead loads upon a beam fixed at one end and loaded near the other end.

There is scarcely anything in engineering construction so actively the subject of depreciating conditions.

The top is exposed to the weather, and the important section near the surface of the ground is the portion most energetically attacked by decay. The wood is assailed by animal life, whether it be gnawing by horses in town, or the perforation by woodpeckers in remote districts. Poles in wild countries are bitten by bears in search of bees, whose humming is imitated by the vibration of wires, and it is said that in India the tigers use the poles to sharpen their claws upon after the manner of their second cousins, the domestic cat, but with so much more vigor that the poles become weakened.

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Not only are they wrecked by storms, but freight-car roofs frequently fly off and strike the poles edgewise with destructive results.

Iron poles are but rarely used in this country, the principal condition governing their selection being on some lines in prairie countries in the West where campers are so prone to cut down wood poles for fuel, that tubular iron poles have been substituted. In Europe there are many iron poles, and in tropical countries infested with white ants it is necessary to use iron poles or to attach the wires to living trees.

Antiseptic methods for treating poles as a preventive against decay and the attacks of insects have not been so general in the United States as in Europe, as the relatively sparse settlement and distances between cities having the elaborate plant necessary for treatment would make the transportation of the poles for treatment and back to the sites where they are to be used a prohibitive expense.

However, poles treated by creosoting have been used in this country wherever transportation conditions between the saw mill, the treating plant and the sites where they are to be used will permit.

These conditions apply to certain portions of the South, where southern pine is sawed to dimensions and then treated.

As the cost of this treatment is based on the volume of the timber, these poles are sawed to such proportions of taper as to give the most economical volume of timber to resist the stresses to which the pole is subjected. The breaking point of these poles, as computed, is from eight to ten feet above the ground.

While gravelly soil will hold a pole to the limit of its strength, it is necessary to build lines in many places where such conditions do not occur. The New Orleans and Mobile line, along the north shore of the Gulf of Mexico, traverses marshes composed of soft mud which extends to a great depth, upon which a rank sedge grass grows twelve to fifteen feet in height, whose coarse roots form a compact mass about a foot in thickness.

In order to prevent this line from being injured by the fires which rage among these marshes in the early spring, the grass is kept cut to a width of one hundred feet along the route.

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It has been possible to sustain poles along this route by bolting heavy cross pieces across them at the ground level, having cut an opening among the roots through which the butt of the pole can be inserted, and then the pole is braced as occasion may require sometimes in four directions, each of these braces being supported on a cross piece at the marsh level. In some instances a pair, or even three, poles are used, each being attached to the same cross-arm.

At the Tybee marshes, near Savannah, Ga., the ground is so soft that it cannot be walked upon, and the men engaged in building the line were obliged to lay a line of boards to proceed along the route. When a pole was to be set, cross pieces were temporarily attached to it near the lower end, and men standing upon these supports "jounced" in unison while the pole was held vertically by pikes.

Under this human pile driving, the pole sank rapidly, but the mud is so adhesive that in a short time the pole is securely held.

Similar methods are used in building the lines across the New Jersey flats, although the conditions are not so severe as at some places farther south.

When ground is too wet and soft to permit digging, poles are frequently set by hewing their butts to wedges, and while the pole is held in a vertical position it is grasped by cant hooks and twisted back and forth, causing it to sink, like the ordinary motion used in boring a hole in wood with a brad awl.

When once set, the pole is either held securely by braces or guys, or it may be made firm by driving a wood curb around it, excavating the mud between the curb and the base of the pole and filling the space with concrete.

In sandy soils, particularly in New Jersey, poles are set on the principle of the jet pile, wherever there is a supply of water.

A half-inch pipe about six feet in length is temporarily attached to the side of the pole, with its lower end at the butt. The other end of the pipe is attached to a garden hose, and when the pole is up-ended the stream of water makes a quicksand into which the pole sinks until the water is shut off, and the pole is sustained by pikes until the water settles, leaving the pole securely held by the sand, which becomes water-packed around it.

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In mountainous countries the ledges are an impediment to excavations for poles, and although dynamite is frequently used, yet poles are set upon rock without excavation and a large number of stones are piled around them in such quantities as to grip the poles securely, although guys are generally necessary.

A pole line is not designed merely on the basis of the stresses to which the pole is subjected in drawing the wires to the necessary tension, for in most northern climates the sleet will at times form upon the wires until they become icy cylinders perhaps three inches in diameter, and the problem is not that of the mere added weight, for the force of the wind blowing against this icy sail applies a greater horizontal load, which combines with gravity and produces a resultant force in a diagonal direction, greater than either of the contributing units.

An ice laden line swayed by the wind may be successfully resisted by the poles until the oscillations of the pendulum reach a synchronism with that of the vibration of some pole on the line which responds in like manner to the cumulative impact across the direction of the line, until it breaks this individual pole. Then adjacent poles are relieved of the pull on one side, and the excessive stress breaks them.

Such is the story of a wrecked aerial line, broken by stresses not included in the ordinary course of events, and which must be provided for by large factors of safety.

It is indeed fortunate that meteorological conditions furnishing in sequence rain at just above a freezing temperature, and meeting a colder stratum, without wind, near to the earth, but followed by a gale, are rare and generally are limited to a small area, for they present conditions which cannot be fully circumvented.

Officers of the Weather Bureau reported in connection with a sleet storm of unusual severity, that there had not been similar conditions in that locality for twenty-three years.

The breakages of lines resulting from a severe storm in Southern New England, a few years ago, revealed the fact that the damage was confined to the valleys of the rivers emptying into Long Island Sound, while the storm did not appear to be of sufficient severity to cause any damage to the lines on higher land.

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It is claimed that sleet never forms to a destructive extent on the wires in certain portions of the northerly part of the United States, and this may be one of the instances of the rarity of such occurrences.

A pole is not to be compared to a mast upon a vessel, for these extreme conditions of severe exposure to telephone lines occur in winter, when the ground is frozen, and holds the base of the pole rigidly, while a vessel in a gale heels when struck by puffs and the sails "spill the wind," and in this manner the masts sustain exposure to winds which would break them if held rigidly to long continued impact.

Aerial Wires.

The aerial wires are so visibly in evidence, and often to an obstructive extent, that they may be cited as the portion of the system which naturally receives especial attention from the public.

Before presenting instances of construction, it is worth while to submit two matters of principles of aerial lines and materials.

The tension on a line suspended between a pair of horizontal supports varies with the sag and is at a minimum when the sag amounts to $\frac{7}{20}$ of the span, and the tension increases whether the sag is greater or less than this proportion.

For example, with No. 12 hard drawn copper wire, weighing 173 pounds to the mile, and being .104 inches diameter, and having a span of 130 feet, the minimum tension of 3 pounds would occur if the sag was 43 feet 6 inches, while it would slowly augment with increase in the sag, and if nature had furnished a chasm deep enough for the experiment, it would be expected to reach its breaking tension of 550 pounds at a depth of 16,470 feet, or 3.17 miles.

On the other hand, the increase in tension proceeds rapidly as the wire is drawn to approach a straight line, the breaking tension occurring at a sag of $1\frac{1}{2}$ inches.

As a comparison with this instance of the stresses in a local line, in the case of the No. 8 hard drawn copper wire, .165 inch

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in diameter and weighing 435 pounds to the mile, as used on long distance telephone lines, when the span is 150 feet the minimum tension occurs at a dip of 52 feet 6 inches, when it is only 8¾ pounds, and in like manner, as in the foregoing instance, its breaking stress of 1,328 pounds would be reached at the slightly less dip of 16,100 feet, or 3.04 miles, still too great to admit of confirmation by direct experiment; but if the wire was pulled until the sag was $2\frac{2}{10}$ inches, it would require the breaking load of 1,328 pounds.

It is desirable that the wires should be drawn tight enough to prevent them from swaying against each other; but it is important that they should not be drawn so tight that the contraction during extreme cold weather should cause the wire to break.

The temperature is carefully noted when lines are being drawn, and the sag is left in accordance with a table based on a factor of safety of five computed for the usual lengths of span throughout a range of natural temperatures.

Natural Temperature Fahrenheit.	Length of Span of Hard Drawn Copper Wire in Feet.					
	75	100	115	130	150	200
	Sag in Inches.					
—30	1	2	2½	3½	4½	8
+10	1½	3	3½	4½	6	10½
+30	2	3	4	5½	7	12
+60	2½	4½	5½	7	9	15½
+100	4½	7	9	11	14	22½

Long Spans.

Where lines traverse mountainous districts or water courses it is frequently necessary to build spans of great length, using either one of the special bronzes or steel wire for the purpose.

The Connecticut River at Middletown is crossed by wires having a span of 1,350 feet, suspended between a steel trussed tower

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185 feet high on the east side, and a similar tower on the bluff on the west bank is 85 feet high.

From Enfield to Windsor Locks the Connecticut is spanned by a suspension bridge consisting of two steel cables one inch in diameter and 955 feet long, to which are fastened 2-inch by 3-inch joists 4 feet 4 inches long set 12 inches on centers. On this bridge are laid four cables containing 100 pairs of wires. The tower on the west bank is 45 feet high and the one on the west bank 33 feet high.

The St. Francis River, near Madison, Ark., is crossed by a span of 1,000 feet, with the wires supported upon steel trussed towers 100 feet in height, as it was necessary that the wires should be clear of steamers on the river, which has a varying level of 30 feet between flood and drought.

At the Raritan Canal crossing, near New Brunswick, N. J., a 60 foot span is raised 112 feet above the canal to avoid the shipping.

There are numerous long spans crossing ponds and rivers not used for navigation at which it is not necessary to erect such high towers or to draw the wires up to a small dip to avoid masts.

Long spans are frequently strung in cases of emergency, as when the flood of June 2, 1903, carried away the bridge crossing the Kaw River at Kansas City, Mo., and also the wires attached to it, a span of wires 900 feet in length was immediately suspended between high spars erected on either bank.

The Missouri River at this city is crossed by a span of 1,500 feet, consisting of fifty No. 8 bronze wires suspended between steel trussed windmill towers 80 feet in height.

The Delaware River at Yardley, Pa., is crossed by an aerial span of 1,300 feet in length with a dip of ten feet. In all instances, it is necessary to use great care in the anchorage of these long spans, for a rigid attachment would cause the wires to become broken when swayed by the wind.

In some instances it has proved sufficient to carry the wires through semicircular grooves cut into a curved wood saddle upon each of the towers at the ends of the span, but the recurrence of breakages has been stopped in other cases only by attaching the

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saddles to springs which will yield to the impact resulting from swaying wires.

The very long spans constructed across the Mississippi, Hudson and Susquehanna Rivers have been advantageously replaced by submarine cables.

Mountain Work.

The most spectacular work in line construction has been done among the mountain ranges of the West.

Lines have been built against the face of cliffs bordering deep canyons, where it was necessary to incline the poles so that the tops carrying the wires overhang the deep abyss, in order to avoid icicles and avalanches falling down the precipice.

In building telephone lines through this mountainous country, a couple of poles are slung like panniers on the sides of two or three mules tandem, and these sure-footed animals will carry them along the rough trails.

The wire is wound in great lengths in connecting coils, which are placed on the sides of the saddles of a train of pack mules, which are thus connected on one side by wire from coil to coil, around the front of the foremost mule and thence back along the other side of the train.

By removing the last pair of coils and unreeling, and thence in turn to the next coil, the pair of wires for a metallic circuit can be laid down along a route.

The Mosquito Pass, near Leadville, Colo., was crossed at an elevation of 13,130 feet by a line of poles which were set only 15 feet apart at the more exposed places, but even this construction did not resist the storms of winter.

Telephone lines were afterwards maintained through this Alpine exposure by an expedient as far out of the ordinary as the celebrated venture of Lord Timothy Dexter in sending warming-pans to the West Indies, and that was by replacing the line of poles by submarine cable carried to this elevated site in continuous coils, as in the case of wire transportation over the mountain

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trails upon a train of mules, and laid in trenches among the rocks to avoid any disturbances from avalanches.

There have been instances when it was necessary to make expeditions to these altitudes in severe weather to make repairs.

The rough valleys through which the routes pass are picturesque in summer, but in winter the snow accumulates to such depths that linemen attend to their duties on snow-shoes, reaching the lines on 25-foot poles as if they were wire fences.

A surveying party, arranging for the extension of some of these lines, found the snow to be 20 feet deep in these basins in the middle of July, while avalanches had rolled down opposite sides of a valley, leaving a narrow pass bordered by snow and ice 100 feet in height.

These lines running from the valleys up to great elevations on the mountains are charged with atmospheric electricity, particularly in winter, which is discharged to earth by bridging retardation coils across the lines and grounding the central part of the coils.

The surveying party noted that these disruptive discharges of static electricity occurred about 16 times a second, producing a continuous sound which could be heard by one near to the wires. The mountain appeared to be enveloped by static electricity, the poles and the engineers' transit glowed with St. Elmo's fire, and an irritation was felt at the head, and the hair would fly up if the hat was removed.

This electric envelope did not appear to extend to the ground, as one was entirely free from any sensations when lying down, but if, while in such a position, a hand was raised to about three feet above the ground, a sharp sputtering sound of static electrical discharges would occur.

Other continuous structures are used for conveying large numbers of wires, especially bridges and the elevated railways in cities.

Underground Conduits.

The number of wires necessary to supply the patronage in cities so far outnumbered the possible capacity of pole lines along the streets that it became necessary to place them underground, and

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this required the development of the underground conduit and the telephone cable as new arts.

While fifty-five per cent. of the telephone exchange wires are underground, yet the great number of wires in these conduits in comparison with those upon poles makes the number of miles of pole lines throughout the country seventy times the length of the streets occupied by underground conduits.

The first experimenters upon underground systems attempted to make them water-tight, and also insulators, such as a solid mass of asphalt concrete in which wires, frequently without insulation, were imbedded.

The lack of satisfactory results caused the Bell Telephone Company to begin the development of the work under Mr. Joseph P. Davis, Chief Engineer, on the principle of providing a conduit of substantial construction containing ducts in which the cables could be placed or withdrawn, and relying upon the conduit merely to provide a protection against injury.

A conduit was built in Boston in which the ducts consisted of three-inch iron casing pipes treated by the hot coal tar process to defend against rusting, which were imbedded in a concrete of eight parts of fine roofing pebbles to only one of cement, and this has remained in good order for twenty-two years.

The manholes were made of brick, covered on the outside with coal tar, and the foundations laid on plank covered with coal tar before the bricks were laid.

This construction was afterwards used in New York, but there was not a sufficient supply of iron casing pipe in the market to supply the demand, and as it was necessary that the work should proceed as rapidly as possible, other materials for ducts were also used.

Logs were bored from end to end and then squared parallel to this core, and sockets and plugs to fit cut at alternate ends to bring the cores securely in line. The wood was treated by the creosoting process before the logs were laid.

Cement-lined sheet-iron pipe imbedded in concrete was also used in large quantities.

At a later date vitrified clay conduit was introduced, and has been extensively used.

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Other materials and methods have been used, notably wood pulp tubes treated with indurating materials to render them impervious to water and a defence against decay.

Tunnels for underground cables have been dug through the soft limestone underlying the city of St. Paul, and one of the largest engineering works of the day is the extensive system of tunnels under the streets of Chicago, which has provision for cables as well as the transportation of material.

In rare instances short tunnels are built, as under the canal and railroad at Trenton, N. J.

In addition to the usual difficulties which beset all constructions under highways, the size of the manholes or underground chambers which afford places for splicing cables or changing their direction, as well as leading them from the conduits to centres of distribution, where the individual pairs of wires branch to the service of patrons, the size of these manholes render other occupants under the streets serious obstructions.

When underground conduits were first built in an eastern city, the engineer prepared sets of standard drawings, and so many were the modifications rendered necessary by other underground work that only one manhole was built in conformity to the standard design.

If the underground conduits remove conductors from vicissitudes of decay of poles, and exposure to storm and the hazards of foreign currents, yet the underground conduits have their share of mishaps.

Breaks in water pipes or sewers disturb the foundations of these conduits, rain storms flood them, illuminating gas percolates into them waiting to be ignited by a spark from a horse's shoe at some leak around a manhole cover, or it may be lighted by men going to work in a manhole with a lantern looking for trouble — and finding it.

The superficially attractive proposition of joint conduit systems, particularly in connection with a scheme of municipal conduits for all electric wires, has been attended by serious occurrences.

Crosses among high tension conductors in cables occur from time to time, and if the wires of signalling systems were exposed in the narrow limits of a manhole, they would be disabled.

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In one city where an inclusive conduit was laid by the municipality, the work was fortunately in good hands, and the manholes were built very large, with the cables of various classes placed on supports upon opposite sides of the manholes, and the cables containing high tension wires were enveloped with split underground tile conduit tied together.

Cables.

The necessity for cables was coincident with the decision that underground conduits must be constructed on the "drawing-in" and not on the "built-in" system, and at about the same time it was foreseen that aerial cables must replace the open wiring in cities wherever there were a great number of local wires, on account of their compactness, and greater resistance to storms. For electrical reasons, it is necessary that open wiring must be used for long telephone lines.

The first telephone cables, both aerial and submarine, are believed to have been those used at Philadelphia in 1881, and at that time experimental constructions were being made at Providence, Brooklyn and Boston.

In the latter city parallel rubber covered wires, giving conditions of such great electrostatic capacity that a mile was the utmost limit of telephonic transmission, were tried, but when about a third of a mile was inserted in a telephone line, subscribers complained that their instruments were becoming worn out, as they could barely hear; and the induction between the parallel wires was so great as to transmit cross talk between the various circuits.

The induction was stopped by placing the wires in twisted pairs, but the problem of insulation with a low static capacity required long experimentation by many persons.

The drawing in of underground cables is like the traction of locomotives, an instance of the occurrence of the unexpected. They can be drawn through devious ducts, around turns and across manholes, to an extent which was not anticipated. The early cables were wound with steel wire twisted on a long pitch to carry the stress of drawing in the cable.

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Experiments on one drawn through an irregular conduit showed that the pull was about twenty tons, but such severe treatment is now avoided as unnecessary.

The cables are usually drawn in by man power, either direct or applied to hand winches, but of late mechanical power has been applied to this work. Automobiles have been used for this work, but a cheaper and more efficient means has been reached by a seven horse-power gasolene engine on a platform wagon, which also carries a winch, a blower to ventilate the manhole and a small generator to illuminate it by incandescent lights.

In advance of a cable, the ducts must be first traversed by a wire to draw the cable, and the forerunner of this wire is either a number of wood rods hooked together and pushed along as section by section is added, and when the length to the next manhole is completed a strong wire is attached to the last rod, and as the first rod is pushed into the next manhole it is inserted in the corresponding duct on the other side of the manhole and pushed and pulled along, or if it is at the end of the cable run, the rods are pulled along and disjointed section by section.

A fine wire is sometimes drawn through a duct by a conical piece of wood with a thin leather washer filling the duct, and forced ahead by the air pressure at the rear, which is exerted through the application of an air pump at the front end of the duct at the next manhole.

This piece of wood is termed the "mouse," and the name is probably responsible for the persistent story that lines are first drawn through the conduits by a fine string tied to the tail of a tame rat which has been taught to do this work.

Cables are applied for miscellaneous other uses outside of conduits wherever the lines need protection against water, moisture or accidental violence. They are used for submarine lines at bridge draws and river crossings, where they appear to be the especial targets for fouling anchors and snarling propellers. The cables across the Mississippi at New Orleans become overlaid by the soft viscous mud of the river, which is so tenacious that it is impossible to pull them up again.

They are applied in tunnel work and in mining, and have even been led to a stranded steamship.

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At Honolulu there are special facilities for laying temporary cables to vessels anchored in the harbor, furnishing them with telephone service when in port.

In all United States seaports, vessels moored to wharves can promptly obtain temporary telephone service, for which wires already are placed upon the wharves ready to be extended to telephones to be installed in the cabin.

The subscribers are reached from underground cables by leading the cable through a pipe from the manhole, thence turning upward at the side of a pole, near the top of which the cables terminate in a cable box and the wires are separated into their several pairs, distributing to their respective instruments, generally by twisted pairs hung upon poles in rear alleys or attached close to buildings to avoid articles falling from windows or ice from roof cornices.

Although lead-covered underground cables entering buildings or kept in storage are frequently gnawed by rats, which receive a swift retribution in case of cables containing high-tension circuits, yet aerial cables have of late received the attacks of insects which cut through the lead sheaths with their sharp mandibles for the purpose of laying eggs in the interior.

The Rate of Telephone Development.

It has been the endeavor to submit, as far as facilities for illustration provide, some of the obstacles presented by natural conditions to the construction and maintenance of telephone lines, in order to secure an appreciation of the engineering skill which has overcome these obstacles to the extension of the telephone service which now knits together in one system over 26,000 different settlements throughout this country.

The establishment of this vast plant from small beginnings was attended for some years with a rate of increase which may appear slow in the light of later events, until the full development of long line service unified the whole in one connecting system the value of whose service is far in excess of what could have been derived from isolated plants in separated towns.

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These wider facilities endowed the telephone service with a higher value whose worth was appreciated, and the installation of telephones became stimulated to such a degree as to tax the resources of the various departments engaged on the work.

During the last five years the number of telephones in the system has increased at a greater rate than ever before. This increase has been building upon itself like compound interest at the usurious rate of 29 per cent. a year, and compounding each year at this rate would double the number in 2¾ years, or the number of telephones has actually increased over 3½ times during the last five years.

Each of these instruments as soon as installed comes into full service for connection with other instruments, and thus reciprocally each new telephone adds to the availability and, therefore, the value of those with which it may be in communication.

During the last five years these additions of 29 per cent. a year have required corresponding amounts for the enormous increase in construction of new plant, which is entirely separate from the maintenance and repairs of the existing property.

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THE DISTRIBUTION OF PRESSURE AND CURRENT OVER ALTERNATING CURRENT-CIRCUITS.

By A. E. Kennelly, D. Sc.

(*Continued from p.* 165, *Vol. IV, No.* 3.)

General Line Conditions.

In the case of a direct-current circuit, A B C as in Fig. 7, if there be no leakage; *i. e.* if g = 0, we have, by Ohm's law, the following

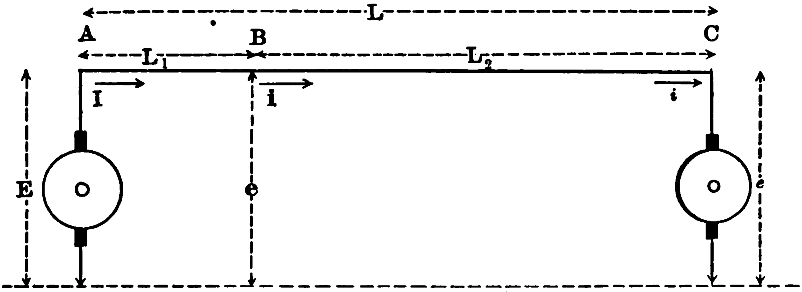

Fig. 7.— Diagram of Simple Ground-Return Circuit; A Generator End, C Motor or Receiving End, B Intermediate Point.

simple relations between the pressure e and current i at any point B, whose distances from ends A and C are L_1 and L_2 miles (or kilometres) respectively, and after the steady state of current in the circuit has been attained:—

$$\mathrm{E} - \mathrm{I}\,\mathrm{L}_1 r = \mathrm{e} = e + i\,\mathrm{L}_2 r \qquad \text{volts} \quad . \quad . \quad . \qquad (24)$$

$$\mathrm{I} = \mathrm{i} = i \qquad \text{amperes} \quad . \quad . \quad . \qquad (25)$$

where E and I are the pressure and current at the generating end A; while e and i are the pressure and current at the receiving end C.

If, however, the same direct-current circuit possesses a uniform leakance of g mhos per mile or kilometre; then the above relations become:—*

$$\mathrm{E} \cosh \mathrm{L}_1 a - \mathrm{I} r_0 \sinh \mathrm{L}_1 a = \mathrm{e} = e \cosh \mathrm{L}_2 a + i r_0 \sinh \mathrm{L}_2 a \qquad (26)$$

$$\mathrm{I} \cosh \mathrm{L}_1 a - \frac{\mathrm{E}}{r_0} \sinh \mathrm{L}_1 a = \mathrm{i} = i \cosh \mathrm{L}_2 a + \frac{e}{r_0} \sinh \mathrm{L}_2 a \qquad (27)$$

* Harvard Engineering Journal, May, 1903.

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where $a = \sqrt{r\,g}$ and $r_0 = \sqrt{\frac{r}{g}}$. In this case the quantities sinh L_1a, cosh L_1a; sinh L_2a, cosh L_2a are the hyperbolic sines and cosines of the real numerical quantities L_1a and L_2a respectively.

Again, if the same circuit A B C of Fig. 7 be converted into a single-phase simple alternating-current circuit, by substituting an alternator at A and an impedance z_r, or a motor c. e. m. f. at B, we obtain:—

$$E \cosh L_1a - Iz_0 \sinh L_1a = e = e \cosh L_2a + iz_0 \sinh L_2a \quad (28)$$

$$I \cosh L_1a - \frac{E}{z_0} \sinh L_1a = i = i \cosh L_2a + \frac{e}{z_0} \sinh L_2a \quad (29)$$

where a and z_0 are defined by (10) and (16) respectively and where L_1a and L_2a, the attenuation-lengths, are plane-vector quantities, or complex numbers, of the type $L(a_1 + ja_2) = La \underline{\left| \tan^{-1} \frac{a_2}{a_1} \right.}$. Each has a numerical magnitude La, at an angle with the datum line, whose tangent is $\frac{a_2}{a_1}$. This ratio $\frac{a_2}{a_1}$ of the imaginary component to the real component may be called the *imaginary-real ratio*. Equations (28) and (29), applying to alternating-currents, are symbolically the same as (26) and (27), applying to direct-current circuits; but differ therefrom in being vector equations instead of simple trigonometrical equations. Moreover, if the terminal conditions E and I at A; or e and i at C, are given in effective values; *i. e.* root-of-mean-squares, as indicated by ordinary good voltmeters and ammeters; then e and i, the conditions at any intermediate point along the line are likewise evaluated by formulae (28) and (29) in effective or r. m. s. values. If, however, E and I; or e and i, are given in maximum cyclic values; then e and i are likewise evaluated by (28) and (29) in maximum cyclic values.

Formulae (28) and (29) contain two pairs of equations. One pair involves the conditions at A. The other pair involves the conditions at C. One or other of these two sets of conditions is usually known in any practical problem, and either is thus sufficient to determine a solution of e and i anywhere along the line.

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In some cases, however, the ratio of e and i is known; but only one terminal current or pressure is forthcoming. In that case we have from (28) and (29)

$$\text{E sech } L_1 a - i z_0 \tanh L_1 a = e = e \text{ sech } L_2 a + i z_0 \tanh L_2 a \qquad (30)$$

$$\text{I sech } L_1 a - \frac{e}{z_0} \tanh L_1 a = i = i \text{ sech } L_2 a + \frac{e}{z_0} \tanh L_2 a \qquad (31)$$

Case of a Line Open-circuited at the far End.

If we free the end of a line remote from the alternator, the current at that end becomes zero, and we obtain from the left-hand side of (30)

$$e = \text{E sech } L_1 a \qquad \text{volts} \quad . \quad . \quad . \quad . \quad . \qquad (32)$$

Since L_1 is in this instance the full length L of the line from A to C, the open-circuited point, we may write the formula

$$e = \text{E sech } La \qquad \text{volts} \quad . \quad . \quad . \quad . \quad . \qquad (33)$$

Consequently, the voltage at the distant end of the open-circuited line, as shown by a voltmeter at C, would be the hyp. secant of the attenuation-length times the voltage impressed at A. The attenuation-length is a vector, and so is its secant. The following table gives the hyp. secant for attenuation lengths up to 1.5, in fifteen successive steps of 0.1, for the five imaginary-real ratios 1, 2, 3, 4 and 10. *i. e.* for the angles 45°, 63°.26′, 71°.34′, 75°.58′ and 84°.17′ respectively.

Table VI.

Sech La, Hyperbolic secants of vector attenuation-lengths La $\left|\tan^{-1}\frac{a_2}{a_1}\right.$

La	1		2		3		4		10	
	Vector	—Angle	Vector	—Angle	Vector	—Angle	Vector	—Angle	Vector	—Angle
0	1.0000	0°.00′	1.0000	0°.00′	1.0000	0°.00′	1.0000	0°.00′	1.0000	0°.00′
0.1	1.0000	0°.17′	1.0030	0°.14′	1.0040	0°.11′	1.0044	0°.08′	1.0049	0°.04′
0.2	0.9999	1°.09′	1.0120	0°.56′	1.0162	0°.41′	1.0179	0°.33′	1.0199	0°.14′
0.3	0.9993	2°.35′	1.0272	2°.06′	1.0369	1°.35′	1.0409	1°.15′	1.0458	0°.31′
0.4	0.9979	4°.35′	1.0485	3°.47′	1.0667	2°.52′	1.0744	2°.16′	1.0838	0°.57′
0.5	0.9949	7°.08′	1.0759	6°.01′	1.1065	4°.36′	1.1199	3°.38′	1.1362	1°.33′
0.6	0.9894	10°.16′	1.1099	8°.52′	1.1579	6°.51′	1.1793	5°.26′	1.2061	2°.19′
0.7	0.9806	13°.53′	1.1487	12°.22′	1.2219	9°.40′	1.2553	7°.44′	1.2984	3°.20′
0.8	0.9675	18°.00′	1.1926	16°.37′	1.2998	13°.13′	1.3516	10°.39′	1.4205	4°.39′
0.9	0.9494	22°.34′	1.2390	21°.41′	1.3930	17°.38′	1.4726	14°.22′	1.5840	6°.22′
1.0	0.9256	27°.29′	1.2850	27°.36′	1.5025	23°.07′	1.6234	19°.09′	1.8073	8°.41′
1.1	0.8963	32°.41′	1.3259	34°.26′	1.6296	30°.02′	1.8081	25°.19′	2.1222	11°.56′
1.2	0.8614	38°.05′	1.3553	42°.06′	1.7496	38°.08′	2.0262	33°.19′	2.5873	16°.44′
1.3	0.8222	43°.35′	1.3669	50°.28′	1.8623	47°.59′	2.2613	43°.39′	3.3047	24°.21′
1.4	0.7793	49°.05′	1.3557	59°.18′	1.9360	59°.15′	2.4677	56°.34′	4.4703	37°.40′
1.5	0.7344	54°.13′	1.3208	68°.18′	1.9463	71°.23′	2.5682	71°.34′	5.9277	62°.16′

N. B. All the angles in this table are negative.

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The table shows that the hyp. secant of a vector attenuation-length always commences at unity for La = 0, and then follows a spiral path. If the imaginary-real ratio of the vector attenuation-length is unity, or less than unity, the hyp. secant immediately begins to dwindle in magnitude, and continues to do so. If, however, the imaginary-real ratio is greater than unity, the hyp. secant increases at first, and may become large for a large imaginary-real ratio. Thus for the ratio $\frac{a_2}{a_1} = 10$ corresponding to an angle of 84°.17′, the hyp. secant has reached $5.9277\,|\overline{62^\circ.16'}$ at $\dot{L}a = 1.5$.

Figure 8 contains the graphs of the hyp. secants recorded in

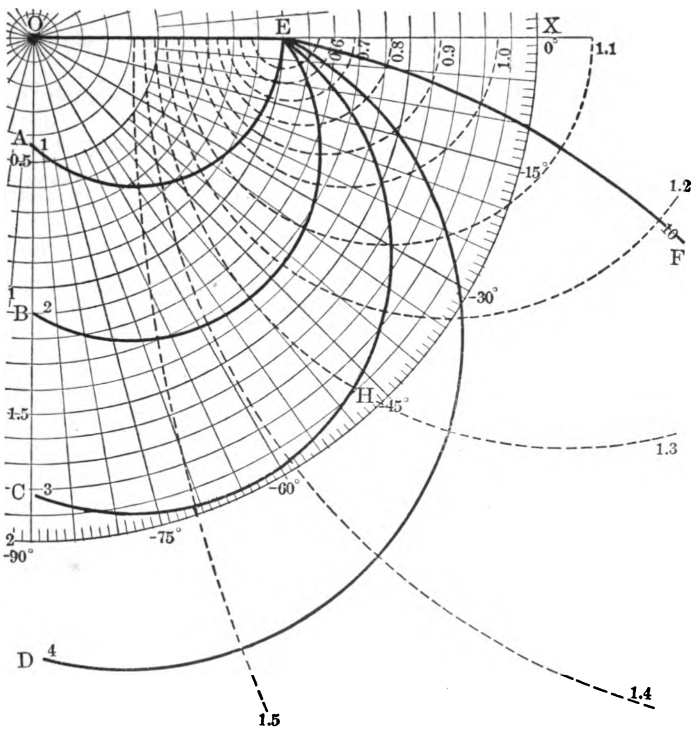

Fig. 8.— Loci of Sech La for the Imaginary-Real Ratios 1, 2, 3, 4 and 10.

Table VI. The line OE on the axis OX is taken as of unit length and standard phase. The heavy lines EA, EB, EC, ED, and

EF, closely approximating circular arcs, are the graphs of the hyp. secants for the vectors whose imaginary-real ratios are 1, 2, 3, 4, and 10 respectively. The broken intersecting curves, also closely approximating circular arcs, marked 0.6, 0.7, 0.8 to 1.5, correspond to the attenuation-lengths in Table VI.

It will be seen that, as far as the curves are carried, the maximum value attained by the vector of imaginary-real ratio

1 is	1	$\lfloor 0^\circ$	at La	$= 0$
2 "	1.37	$\lfloor 50^\circ.30'$	" "	$= 1.303$
3 "	1.95	$\lfloor 65^\circ$	" "	$= 1.464$
4 "	2.6	$\lfloor 73^\circ$	" "	$= 1.515$
10 "	6.35	$\lfloor 90^\circ$	" "	$= 1.57$

For ratio values of more than 4, the first maximum is nearly attained at $La = \frac{\pi}{2}$ = or 1.5708, and this maximum is numerically equal to cosech La_1 at that point. By taking an imaginary-real ratio large enough, the first maximum may be made numerically as great as we please.

Applying the above considerations to formula (33) it is evident that since the angle of an attenuation constant is always over 45°, unless there be leakance, or waste of energy in the dielectric, the voltage at the distant open ends of a well insulated circuit tends to be greater than that impressed at the generating end. If the linear capacity of the circuit be large and the inductance be small, there will be little or no rise of potential; for the curve EA of Fig. 8 applies. On the contrary, if the capacity of the circuit be small and the inductance large, the imaginary-real ratio, and the angle, of the attenuation-constant will be relatively large; so that a marked rise of voltage at the distant open end of the circuit is possible. This means that cabled wires are not subject to appreciable rise of voltage at the far open end; but that aerial line wires are subject to that tendency, especially when they are large, well separated, and operated at high frequencies. Thus a pair of #0000 A. W. G. copper wires (diameter 0.46″ = 1.168 cm.) separated interaxially by 72″ (182.9 cms.) would develop an attenuation constant of $0.003{,}665 \lfloor 84^\circ.17'$ per mile ($0.002{,}277 \lfloor 84^\circ.17'$ per kilometre) at the frequency of 105.4 cycles per second. This

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corresponds to an imaginary-real ratio of 10, and the voltage at the distant open end of such a circuit should be 6.35 times the impressed voltage when the attenuation-length was 1.57; *i. e.* when the length of the circuit reached 430 miles (692 kilometres). No such great rise of voltage at the distant open end of a circuit has yet been reported, probably because the lengths of commercial power-transmission circuits are relatively small, and their frequencies of operation low. Nevertheless the general tendency of the voltage to rise at the end of an open line is well known, under the name of the Ferranti effect. Although upper harmonic ripples of e. m. f. on actual lines are capable of producing a several-fold rise at their distant open ends, yet being individually small, and also being compounded vectorially at right angles to the fundamental, or main working e. m. f., their effect in raising the total voltage is small.

If the voltage at any point along the line, distant L_1 miles, or kilometres, from the generating end, is required when the distant end is free, we obtain from (28) and (29): —

$$\mathrm{e} = \mathrm{E}\ (\cosh L_1 a - \sinh L_1 a \tanh La) \qquad \text{volts} . \qquad (34)$$

which expresses the voltage in terms of the impressed e. m. f. and of hyp. functions of L and L_1; or, using the right-hand side of (28) with $i = 0$

$$\mathrm{e} = e \cosh L_2 a \qquad \text{volts} \quad . \quad . \quad . \quad . \qquad (35)$$

$$= \mathrm{E}\ \mathrm{sech}\ La \cosh L_2 a \qquad \text{volts} \quad . \quad . \quad . \quad . \qquad (36)$$

If then we first determine the voltage e at the distant free end, the voltage at any point L_2 miles or kilometres therefrom will be obtained by multiplying into the hyp. cosine of the attenuation-distance L_2a. Table VII gives the hyp. cosine of such attenuation distances up to $L_2a = 1.5$ for the imaginary-real ratios 1, 2, 3, 4 and 10. These cosines are all respectively the reciprocals of the corresponding entries in Table VI. The entries in Table VII are indicated graphically in Fig. 9, where the horizontal line OA is selected as of unit length. The heavy curves A1, A2, A3, A4 and A10 follow the values of the hyp. cosines for the successive tabular entries.

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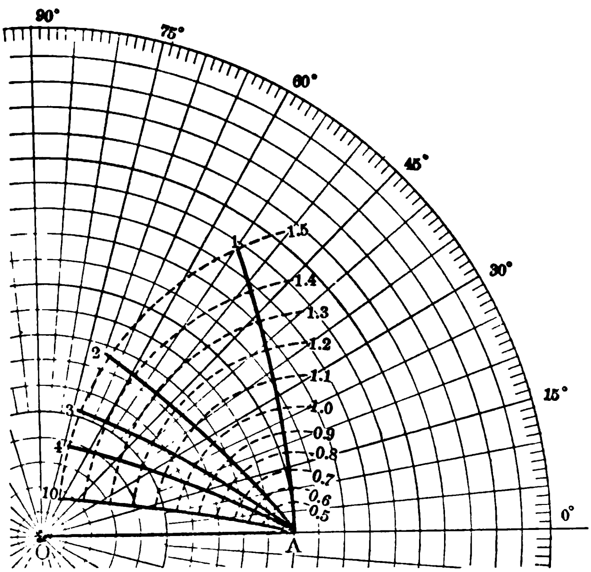

FIG. 9.— Loci of Cosh $L\alpha$ for the Imaginary-Real Ratios 1, 2, 3, 4 and 10.

Table VII.

Cosh $L\alpha$, Hyperbolic cosines of vector attenuation-lengths $L\alpha \left| \tan^{-1}\frac{\alpha_2}{\alpha_1} \right.$

La	1 Vector	1 Angle	2 Vector	2 Angle	3 Vector	3 Angle	4 Vector	4 Angle	10 Vector	10 Angle
0	1.0000	0°.00′	1.0000	0.°00′	1.0000	0°.00′	1.0000	0°.00′	1.0000	0°.00′
0.1	1.0000	0°.17′	0.9970	0.°14′	0.9960	0°.11′	0.9956	0°.08′	0.9951	0°.04′
0.2	1.0001	1°.09′	0.9881	0°.56′	0.9841	0°.41′	0.9824	0°.33′	0.9805	0°.14′
0.3	1.0007	2°.35′	0.9736	2°.06′	0.9645	1°.35′	0.9607	1°.15′	0.9562	0°.31′
0.4	1.0021	4°.35′	0.9538	3°.47′	0.9375	2°.52′	0.9308	2°.16′	0.9227	0°.57′
0.5	1.0051	7°.08′	0.9295	6°.01′	0.9038	4°.36′	0.8930	3°.38′	0.8801	1°.33′
0.6	1.0107	10°.16′	0.9010	8°.52′	0.8637	6°.51′	0.8479	5°.26′	0.8291	2°.19′
0.7	1.0198	13°.53′	0.8706	12°.22′	0.8184	9°.40′	0.7966	7°.44′	0.7702	3°.20′
0.8	1.0336	18°.00′	0.8385	16°.37′	0.7693	13°.13′	0.7399	10°.39′	0.7040	4°.39′
0.9	1.0533	22°.34′	0.8071	21°.41′	0.7177	17°.38′	0.6791	14°.22′	0.6313	6°.22′
1.0	1.0803	27°.29′	0.7782	27°.36′	0.6656	23°.07′	0.6160	19°.09′	0.5533	8°.41′
1.1	1.1157	32°.41′	0.7542	34°.26′	0.6137	30°.02′	0.5531	25°.19′	0.4712	11°.56′
1.2	1.1608	38°.05′	0.7378	42°.06′	0.5716	38°.08′	0.4935	33°.19′	0.3865	16°.44′
1.3	1.2162	43°.35′	0.7316	50°.28′	0.5370	47°.59′	0.4422	43°.39′	0.3026	24°.21′
1.4	1.2832	49°.05′	0.7376	59°.18′	0.5165	59°.15′	0.4052	56°.34′	0.2250	37°.40′
1.5	1.3616	54°.33′	0.7571	68°.18′	0.5138	71°.23′	0.3894	71°.34′	0.1687	62°.16′

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As an example, we may consider a pair of well insulated #10 A. W. G. copper wires 12 inches, or 30.48 cms., apart and operated at a frequency of 5410 radians per second, or 860.8 cycles per second. Reference to table I and Fig. 5 will show that the attenuation-constant for this line and frequency is 0.01945 $\underline{|75^\circ.58'}$ per kilometre (0.0313 $\underline{|75^\circ.58'}$ per mile). The imaginary-real coefficient of this attenuation constant is 4.0, the tangent of 75°.58′. If an e. m. f. of 6 volts is applied to A, the sending end of a pair of such wires 51.41 kilometres (31.94 miles) long, with their distant ends free, what will be the e. m. f. at a point B, Fig. 7, 20.56 kilometres from A? In this case the e. m. f. E applied to each wire in Fig. 2 is 3.0, La = 1.0, and the voltage per wire at the distant end is, by (33), $e = 3 \times \operatorname{sech} 1 \; \underline{|\tan^{-1} 4} = 3 \times 1.6234 \; \overline{|19^\circ.09'}$ by table VI $= 4.870 \overline{|19^\circ.09'}$. Now entering formula (35) with this value of e, and observing that $L_2 = 30.85$ kilometres, $L_2 a = 0.6$; so that $e = e \cosh 0.6 \; \underline{|\tan^{-1} 4} = 4.870 \; \overline{|19^\circ.09'} \times 0.8479 \; \underline{|5^\circ.26'} = 4.129 \; \overline{|13^\circ.43'}$. This being the voltage between each wire and the neutral plane, the voltage across the circuit at B will be 8.258 $\overline{|13^\circ.43'}$ volts.

If the attenuation-length of the line be very small, say below 0.1, neither the curves nor the tables are suitable for determining the voltage at the distant open end. A suitable approximate formula is then obtained by expanding sech La in series, and retaining only the first two terms; viz.:—

$$e = E \left\{ 1 - \frac{(La)^2}{2} \right\} \quad \text{volts} \quad . \quad . \quad . \quad (37)$$

Thus, if $La = 0.1 \; \underline{|71^\circ.34}$, $\frac{(La)^2}{2} = 0.005 \; \underline{|143^\circ.08'}$ and $1 - \frac{(La)^2}{2} = 1.004 \; \overline{|0^\circ.10'}$, agreeing as far as three decimal places with the entry in Table VI.

Similarly, the approximate formula for the voltage at any point along the line, obtained from (36) by expansion, is

$$e = E \left\{ 1 - \frac{(L_1 a)^2}{2} \left(\frac{2L}{L_1} - 1 \right) \right\} \quad \text{volts} \quad . \quad . \quad . \quad (38)$$

Thus, if we desire the voltage at a point $L_1 a = 0.04 \; \underline{|71^\circ.34'}$ in the

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last example, we have $e = E \left\{ 1 - \frac{0.0016 \,|\, \underline{143°.08'}}{2} \left(\frac{0.2}{0.04} - 1 \right) \right\}$
$= E \{ 1 - 0.0032 \;|\underline{143°.08'} \} = E \times 1.0026 \;|\overline{1°.06'}$.

The current strength at the receiving end of the open-circuited line will be zero, and at the sending end, by the right-hand side of (31), will be

$$\left.\begin{aligned} I &= \frac{E}{z_0} \tanh La \quad \text{amperes} \\ &= I_0 \quad \tanh La \quad \text{amperes} \end{aligned}\right\} \quad . \quad . \quad . \quad (39)$$

Since the initial outgoing current is I_0, successive reflections from the distant open end increase this initial current, in the steady state, by the factor tanh La.

Table VIII gives the hyp. tangent of any vector La from 0 to 1.5 in steps of 0.1 for the five angles and imaginary-real ratios already discussed.

Table VIII.

Tanh La, Hyperbolic tangents of vector attenuation-lengths La $\left|\tan^{-1}\frac{a_2}{a_1}\right.$

r	1		2		3		4		10	
	Vector	Angle	Vector	Angle	Vector	Angle	Vector	Angle	Vector	Angle
0.	0.0000	45°.00′	0.0000	63°.26′	0.0000	71°.34′	0.0000	75°.58′	0.0000	84°.18′
0.1	0.1000	44°.48′	0.1002	63°.16′	0.1002	71°.23′	0.1004	75°.53′	0.1003	84°.13′
0.2	0.1999	44°.14′	0.2016	62°.48′	0.2020	71°.07′	0.2027	75°.36′	0.2026	84°.08′
0.3	0.2997	43°.16′	0.3054	62°.02′	0.3074	70°.30′	0.3081	75°.07′	0.3091	83°.57′
0.4	0.3991	41°.56′	0.4128	60°.53′	0.4178	70°.00′	0.4197	74°.25′	0.4223	83°.39′
0.5	0.4977	40°.15′	0.5248	59°.21′	0.5350	68°.35′	0.5395	73°.28′	0.5454	83°.13′
0.6	0.5942	38°.11′	0.6425	57°.21′	0.6620	66°.49′	0.6708	72°.12′	0.6820	82°.40′
0.7	0.6874	35°.47′	0.7659	54°.53′	0.8010	64°.47′	0.8170	70°.30′	0.8380	81°.55′
0.8	0.7756	33°.06′	0.8956	51°.50′	0.9542	62°.09′	0.9828	68°.18′	1.0213	80°.54′
0.9	0.8576	30°.10′	1.0295	48°.09′	1.1243	58°.47′	1.1740	65°.25′	1.2460	79°.33′
1.0	0.9306	27°.03′	1.1650	43°.47′	1.3130	54°.30′	1.3967	61°.36′	1.5268	77°.38′
1.1	0.9939	23°.50′	1.2960	38°.42′	1.5242	49°.01′	1.6667	56°.31′	1.9006	74°.51′
1.2	1.0456	20°.36′	1.4141	32°.40′	1.7280	42°.23′	1.9548	49°.44′	2.4258	70°.35′
1.3	1.0857	17°.27′	1.5100	26°.37′	1.9260	34°.14′	2.2722	40°.46′	3.2070	63°.34′
1.4	1.1141	14°.29′	1.5740	20°.20′	2.0777	24°.52′	2.6070	29°.23′	4.4180	50°.55′
1.5	1.1323	11°.42′	1.6015	13°.56′	2.1500	14°.51′	2.7235	16°.08′	5.9750	27°.04′

The curves of Fig. 10 follow the successive vectors recorded in table VIII, the line OA being selected as of unit length and standard direction.

Thus, taking the pair of well insulated copper wires last con-

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sidered, we find, with the aid of Table III and Fig. 6, that the initial sending-end impedance per wire at the frequency of 860.8 cycles per second is $z_0 = 360.4 \; \lfloor\overline{14°.02'}$ ohms. With say 6 volts applied to such a circuit 51.41 kilometres long (31.94 miles), the e. m. f. per single wire in Fig. 2 would be 3 volts. The initial outgoing current would be $I_0 = \dfrac{3}{360.4 \; |\overline{14°.02'}} = 0.008,324$

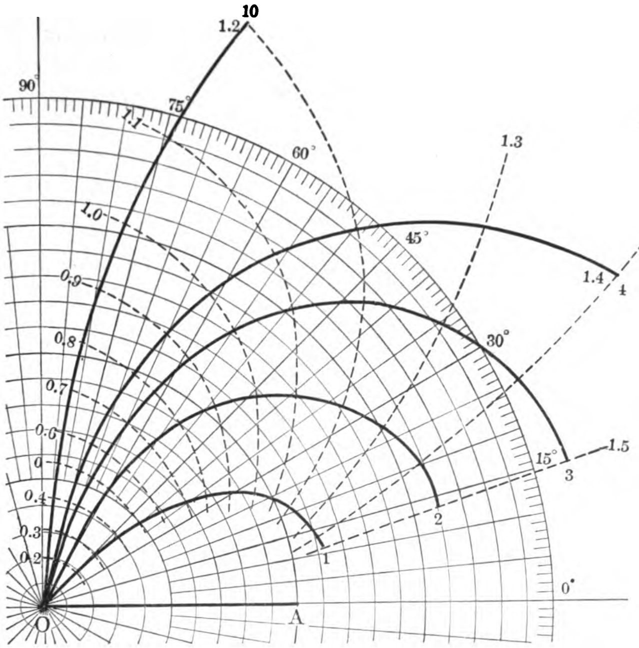

FIG. 10.— Loci of Tanh La for the Imaginary-Real Ratios 1, 2, 3, 4 and 10.

$\lfloor\underline{14°.02'}$ amperes, or 8.324 milliamperes, leading the phase of the e. m. f. by 14°.02′. The current at the sending end in the steady state would be found by multiplying into tanh La, by (39). But for this line, it has already been shown that $La = 1 \; |\underline{\tan^{-1} 4}$ and the hyp. tangent of this quantity is found in Table VIII to be 1.3967 $|\underline{61°.36'}$. Consequently, the current in either wire at the sending of this line, when the distant ends are free, will be $8.324 \times 1.3967 \; |\underline{75°.38'} = 11.625 \; |\underline{75.°38'}$ milliamperes.

At any point along the open line, distant L_1 kilometres or miles from the sending end, the current strength is:—

$$i = I_0 \left(\cosh L_1 a \tanh La - \sinh L_1 a\right) \quad \text{amperes} \quad . \qquad (40)$$

where $\quad I_0 = E/z_0$

Formula (39) shows that the initial sending-end impedance z_0 becomes modified in the steady state, with the distant end free, to a final sending-end impedance:

$$z_A = z_0 \coth La \qquad \text{ohms} \quad . \quad . \quad . \quad . \qquad (41)$$

or is multiplied by the hyp. cotangent of the attenuation-length. Table IX gives these cotangents up to the attenuation-length of 1.5, in steps of 0.1, for the five imaginary-real ratios already referred to.

Table IX.

Coth La, Hyperbolic cotangents of vector attenuation-lengths La | $\tan^{-1}\frac{a_2}{a_1}$

	1		2		3		4		10	
	Vector	Angle	Vector	Angle	Vector	Angle	Vector	Angle	Vector	Angle
0	∞	45°.00′	∞	63°.26′	∞	71°.34′	∞	75°.58′	∞	84°.18′
0.1	10.0025	44°.48′	9.980	63°.16′	9.980	71°.23′	9.960	75°.53′	9.970	84°.13′
0.2	5.0018	44°.14′	4.960	62°.48′	4.950	71°.07′	4.933	75°.36′	4.936	84°.08′
0.3	3.3365	43°.16′	3.274	62°.02′	3.253	70°.30′	3.246	75°.07′	3.235	83°.57′
0.4	2.5050	41°.56′	2.422	60°.53′	2.393	70°.00′	2.383	74°.25′	2.370	83°.39′
0.5	2.0092	40°.15′	1.905	59°.21′	1.869	68°.35′	1.854	73°.28′	1.834	83°.13′
0.6	1.6830	38°.11′	1.556	57°.21′	1.511	66°.49′	1.491	72°.12′	1.466	82°.40′
0.7	1.4547	35°.47′	1.306	54°.53′	1.2484	64°.47′	1.224	70°.30′	1.193	81°.55′
0.8	1.2894	33°.06′	1.117	51°.50′	1.0480	62°.09′	1.018	68°.18′	0.9791	80°.54′
0.9	1.1660	30°.10′	0.9714	48°.09′	0.8894	58°.47′	0.8518	65°.25′	0.8026	79°.33′
1.0	1.0746	27°.03′	0.8584	43°.47′	0.7616	54°.30′	0.7160	61°.36′	0.6550	77°.38′
1.1	1.0061	23°.50′	0.7716	38°.42′	0.6560	49°.01′	0.6000	56°.31′	0.5261	74°.51′
1.2	0.9564	20°.36	0.7071	32°.40′	0.5787	42°.23′	0.5116	49°.44′	0.4122	70°.35′
1.3	0.9211	17°.27′	0.6623	26°.37′	0.5192	34°.14′	0.4401	40°.46′	0.3118	63°.34′
1.4	0.8996	14°.29′	0.6353	20°.20′	0.4815	24°.52′	0.3836	29°.23′	0.2263	50°.55′
1.5	0.8831	11°.42′	0.6244	13°.56′	0.4651	14°.51′	0.3672	16°.08′	0.1674	27°.04′

N. B. All of the angles in the table are negative.

The curves of Fig. 11 have been drawn to correspond with the entries in the above Table.

As an example of the use of Table IX, we may consider a circuit formed of a pair of # 0000 copper wires (diam. 1.168 cm.) interaxially separated by 6 feet (182.9 cms.) and operated at 105.4 cycles per second. Such a circuit has been shown to have an at-

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tenuation constant of 0.002,277 $|\underline{\tan^{-1} 10}$ per kilometre. (0.003,665 $|\underline{84^\circ.17'}$ per mile). The initial sending-end impedance of this line is $z_0 = 358.8 \;|\overline{5^\circ.43'}$ ohms, by (16). The final sending-end impedance per wire, with the distant ends free, by (41) is 358.8 $|\overline{5^\circ.43'}$ ohms, times the hyp. cotangent of the attenuation-length. If the length of the circuit considered be say 54.57 miles (87.82 kilometres), the attenuation-length would be 0.2 $|\underline{\tan^{-1} 10}$, of which the hyp. cotangent is found in Table IX to be 4.936 $|\overline{84^\circ.08'}$. Consequently, the final sending-end impedance is 1,771 $|\overline{89^\circ.51'}$.

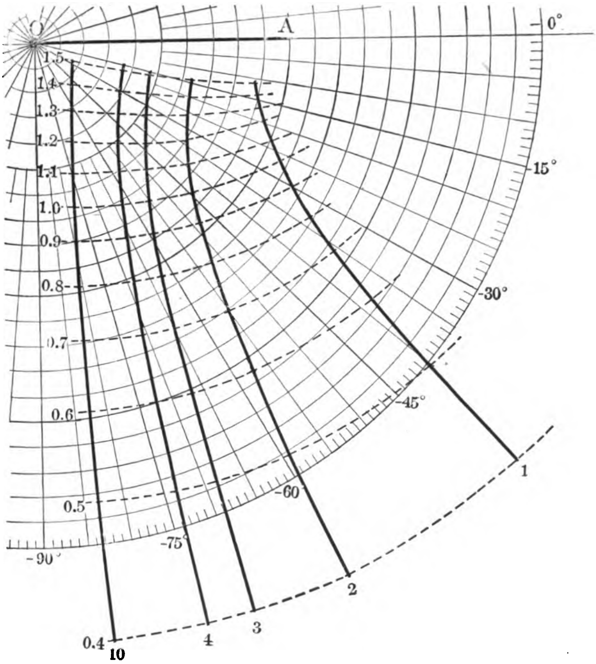

FIG. 11.— Loci of Coth La for the Imaginary-Real Ratios 1, 2, 3, 4 and 10.

ohms. A three-phase transmission line of this length and of three such wires 6 feet apart, if free at the distant end, and connected at the generator end to a three-phase voltage of 30,000 volts in each star-branch (51,960 volts between wires), would take a charging current of $\dfrac{30,000}{1,771 \;|\overline{89^\circ.51'}} = 16.94 \;|\underline{89^\circ.51'}$ amperes per wire.

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In all cases the hyp. cotangent tends to the value $1\underline{|0^\circ}$ as La is indefinitely increased; so that when the length of the line is very great, the final sending-end impedance converges to equality with the initial sending-end impedance. But whereas if the imaginary-real ratio of the attenuation constant is 1, the convergence is rapid, and comes within about 1% at $La = 3$, the convergence is slower as the imaginary-real ratio rises; so that the value of La must be nearly 27, before z_A reaches within 1% of z_0 if the imaginary-real ratio be 10.

If, on the contrary, the attenuation-length be very small, say below 0.1, an approximate formula for the final sending end impedance is

$$z_A = \frac{z_0}{La} \quad \text{ohms} \qquad (42)$$

Thus, in the case last considered, if the length of line be reduced to 27.285 miles (43.91 kilometres); so that $La = 0.1 \,|\overline{\tan^{-1} 10}$, the final sending-end impedance is $\dfrac{358.8\,|\overline{5^\circ.43'}}{0.1\,|\overline{84^\circ.17'}} = 3{,}588\,|\overline{90^\circ.00'}$ ohms; while formula (41) with the use of Table IX would make the correct value $3{,}577\,|\overline{89^\circ.56'}$. For still smaller attenuation-lengths the agreement would improve.

For very large attenuation-lengths, the final sending-end impedance with the distant end free would be as already stated:—

$$z_A = z_0 \quad \text{ohms} \qquad (43)$$

At any intermediate point B, Fig. 7, along the line, the final impedance of the line beyond, with distant end open is

$$z_B = z_0 \coth L_2 a \quad \text{ohms} \qquad (44)$$

Thus the whole line AC of 54.57 miles (87.82 kilometres) above considered would offer, as we have seen, $1{,}771\,|\overline{89^\circ.51'}$ ohms at A to a frequency of 105.4 cycles per second; but if B be taken half-way along the line; so that $L_2 = 27.285$ miles (43.91 kilometres), $L_2 a = 0.1$ and the impedance of the distant section BC as measured at the point B would be $3{,}577\,|\overline{89^\circ.56'}$ ohms.

The Circuit Shorted, or each Wire Grounded, at the Distant End.

If we connect the two wires of a single-phase circuit directly

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together at the distant end, we virtually ground each wire at C in Fig. 3. Consequently, in equations (28) to (31) e = 0. The left-hand side of (30) gives then

$$\left.\begin{aligned} i &= \frac{E}{z_0} \text{ cosech } La \quad \text{amperes} \\ &= I_0 \text{ cosech } La \quad \text{amperes} \end{aligned}\right\} \quad . \quad . \quad . \quad (45)$$

as the strength of the current to ground at the distant end. The final current at the distant shorted end is therefore equal to the initial outgoing current multiplied by the hyp. cosecant of the attenuation-length.

Table X gives these hyp. cosecants up to the attenuation-length of 1.5, in steps of 0.1, for the five imaginary-real ratios already considered.

Table X.

Cosech La, Hyperbolic cosecants of vector attenuation-lengths La $\left| \tan^{-1}\frac{a_2}{a_1} \right.$

	1		2		3		4		10	
	Vector	Angle	Vector	Angle	Vector	Angle	Vector	Angle	Vector	Angle
0.	∞	45°.00′	∞	63°.26′	∞	71°.34′	∞	75°.58′	∞	84°.17′
0.1	10.0025	45°.05′	10.009	63°.30′	10.017	71°.34′	10.010	76°.01	10.021	84°.17′
0.2	5.0011	45°.23′	5.020	63°.44′	5.0301	71°.48′	5.0228	76°.09	5.035	84°.22′
0.3	3.3340	45°.51′	3.363	64°.08′	3.3732	72°.05′	3.3780	76°.22	3.384	84°.28′
0.4	2.5002	46°.31′	2.540	64°.40′	2.5540	72°.52′	2.560	76°.41	2.566	84°.36′
0.5	1.9989	47°.23′	2.0502	65°.22′	2.0680	73°.01′	2.0754	77°.06	2.083	84°.46′
0.6	1.6651	48°.27′	1.7273	66°.13′	1.7488	73°.40′	1.7580	77°.38	1.786	84°.59′
0.7	1.4265	49°.40′	1.4997	67°.15′	1.5255	74°.27′	1.5365	78°.14	1.549	85°.15′
0.8	1.2475	51°.06′	1.3316	68°.27′	1.3622	75°.22′	1.3752	78°.57	1.391	85°.33′
0.9	1.1070	52°.44′	1.2034	69°.50′	1.2391	76°.25′	1.2543	79°.47	1.272	85°.55′
1.0	0.9945	54°.32′	1.1030	71°.23′	1.1442	77°.37′	1.1621	80°.45	1.184	86°.19′
1.1	0.9018	56°.31′	1.0230	73°.08′	1.0689	79°.03′	1.0847	81°.50	1.117	86°.47′
1.2	0.8238	58°.41′	0.9583	74°.46′	1.0125	80°.31′	1.0366	83°.03	1.067	87°.19′
1.3	0.7573	61°.02′	0.9052	77°.15′	0.9670	82°.13′	0.9951	84°.25	1.030	87°.55′
1.4	0.6995	63°.34′	0.8613	79°.38′	0.9319	84°.07′	0.9465	85°.57	1.006	88°.35′
1.5	0.6486	66°.15′	0.8247	82°.14′	0.9051	86°.14′	0.9434	87°.42	0.992	89°.20′

N. B. All the angles in this table are negative.

Fig. 12 shows the loci of the above tabular values.

For example, consider a circuit formed of a pair of twisted #19 A. W. G. copper wires, each of 0.0912 cm. diameter, paper covered in a telephone cable. The attenuation-constant of this circuit, at 159.2 cycles per second, is 0.052,72 $\underline{|45°.22'}$ per kilometre, by Table II and the initial sending-end impedance 530.4 $\overline{|44°.39'}$

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ohms per wire, by Table IV. An alternating e. m. f. of 10 volts at this frequency, applied to the circuit, would give E $= 5 \;\underline{|0^\circ}$ volts per wire. The initial current at the sending-end would be $I = \dfrac{5}{530.4 \;|\overline{44^\circ.39'}} = 0.009{,}427 \;\underline{|44^\circ.39'}$ amperes, or 9.427 milliamperes, 44°.39′ ahead of the impressed e. m. f. in phase. If

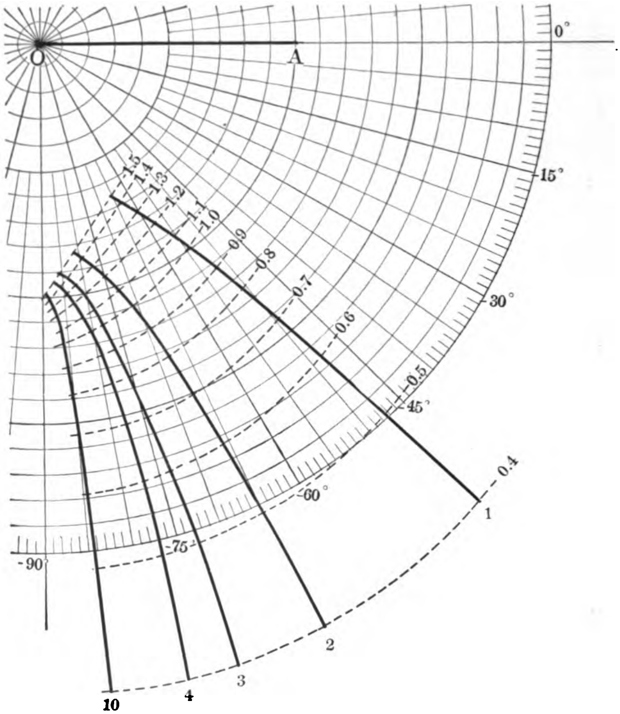

FIG. 12.— Loci of Cosech La for the Imaginary-Real Ratios 1, 2, 3, 4 and 10.

the length of the circuit be 28.45 kilometres (17.68 miles) the attenuation-length will be $1.5 \;\underline{|45^\circ.22'}$. According to Table X, the hyp. cosecant of this value is approximately $0.6486 \;|\overline{66^\circ.15'}$. Consequently, when the circuit is shorted at this length, the final current-strength through the short-circuit at the distant end will be, by (45), $9.427 \;\underline{|44^\circ.39'} \times 0.6486 \;|\overline{66^\circ.15'} = 6.115 \;|\overline{21^\circ.36'}$ milliamperes, approximately.

If the imaginary-real ratio of the attenuation-constant of a

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circuit be only slightly in excess of 1, the current-strength to ground will steadily diminish as the length increases; that is cosech La steadily diminishes. If, however, the attenuation-constant has a large angle and imaginary-real ratio, the cosecant slowly diminishes as La increases, but not steadily, that is, it undergoes fluctuations or successive maxima and minima, its graph being spiral.

The impedance which the line offers, judged by an observer at the distant end C, Fig. 7, when the line is there grounded, is by (45)

$$Z_1 = z_0 \sinh \mathrm{L}a \qquad \text{ohms} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (46)$$

calling this the *receiving-end-impedance*, it is obtained by multiplying the initial sending-end impedance z_0 into the hyp. sine of the attenuation-length. Table XI gives the values of the hyp. sine of La up to La = 1.5, in steps of 0.1, for the five angles, and imaginary-real ratios already considered. The values thus tabulated are also graphically traced in the curves of Fig. 13.

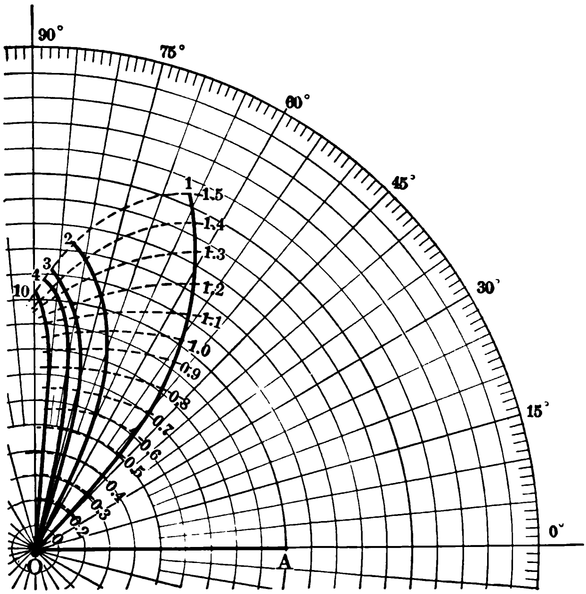

FIG. 13.— Loci of Sinh La for the Imaginary-Real Ratios 1, 2, 3, 4 and 10.

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Table XI.

Sinh La, Hyperbolic sines of vector attenuation-lengths La $\left|\tan^{-1}\frac{a_2}{a_1}\right.$

	1		2		3		4		10	
	Vector	Angle	Vector	Angle	Vector	Angle	Vector	Angle	Vector	Angle
0.0	0.0000	45°.00′	0.0000	63°.26′	0.0000	71°.34′	0.0000	75°.58′	0.000	84°.17′
0.1	0.1000	45°.05′	0.0999	63°.30′	0.0998	71°.34′	0.0999	76°.01′	0.0998	84°.17′
0.2	0.2000	45°.23′	0.1992	63°.44′	0.1988	71°.48′	0.1991	76°.09′	0.1986	84°.22′
0.3	0.2999	45°.51′	0.2973	64°.08′	0.2965	72°.05′	0.2960	76°.22′	0.2955	84°.28′
0.4	0.4000	46°.31′	0.3937	64°.40′	0.3916	72°.52′	0.3907	76°.41′	0.3897	84°.36′
0.5	0.5003	47°.23′	0.4877	65°.22′	0.4835	73°.01′	0.4818	77°.06′	0.4800	84°.46′
0.6	0.6006	48°.27′	0.5789	66°.13′	0.5718	73°.40′	0.5688	77°.38′	0.5655	84°.59′
0.7	0.7010	49°.40′	0.6668	67°.15′	0.6555	74°.27′	0.6508	78°.14′	0.6454	85°.15′
0.8	0.8016	51°.06′	0.7510	68°.27′	0.7341	75°.22′	0.7272	78°.57′	0.7191	85°.33′
0.9	0.9033	52°.44′	0.8310	69°.50′	0.8070	76°.25′	0.7973	79°.47′	0.7865	85°.55′
1.0	1.0055	54°.32′	0.9066	71°.23′	0.8739	77°.37′	0.8605	80°.45′	0.8448	86°.19′
1.1	1.1089	56°.31′	0.9775	73°.08′	0.9355	79°.03′	0.9219	81°.50′	0.8956	86°.47′
1.2	1.2138	58°.41′	1.0435	74°.46′	0.9877	80°.31′	0.9647	83°.03′	0.9377	87°.19′
1.3	1.3205	61°.02′	1.1047	77°.15′	1.0342	82°.13′	1.0049	84°.25′	0.9706	87°.55′
1.4	1.4297	63°.34′	1.1610	79°.38′	1.0730	84°.07′	1.0565	85°.57′	0.9941	88°.35′
1.5	1.5418	66°.15′	1.2125	82°.14′	1.1047	86°.14′	1.0606	87°.42′	1.0081	89°.20′

Thus, taking the cable circuit of twisted pairs of paper covered #19 A. W. G. wires last considered, the initial sending-end impedance, at 159.2 cycles per second, is 530.4 $\underline{|44°.39'}$ ohms per wire. If the length of the line be 28.45 kilometres (17.68 miles), so that $La = 1.5 \quad \underline{|45°.22'}$, the receiving-end impedance with the line to ground at C, will be 530.4 $\underline{|44°.39'} \times 1.542 \quad \underline{|66°.15'}$ approximately, or 818 $\underline{|21°.36'}$ ohms.

When the attenuation-length is relatively large, its hyp. sine approximates to sinh La_1, or the hyp. sine of the real-attenuation length. The receiving-end impedance to ground then approximates to

$$Z_1 = z_0 \sinh La_1 \quad \text{ohms} \quad . \quad . \quad . \quad . \quad . \quad (47)$$

and this also approximates to

$$Z_1 = \frac{z_0}{2} \epsilon^{La_1} \quad \text{ohms} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (48)$$

Thus, if the line above considered had a length of say 113.8 kilometres (70.72 miles), so that $La = 6 \quad \underline{|45°}$approximately; $La_1 = 4.2426$ and sinh $La_1 = 34{\cdot}7834$, which is correct to the third decimal place compared with (46). If we employ formula (48),

$$\frac{\epsilon^{La_1}}{2} = \frac{2{\cdot}71828^{4\ 2426}}{2} = 34.795.$$

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If the imaginary-real ratio be 1, the approximation offered by formula (47) will be within 1% after $La = 3.5$; but as the imaginary-real ratio increases, the attenuation-length rapidly rises before the same degree of approximation is secured.

When the attenuation-length La is, on the contrary, very small; say 0.1 or less, an approximate formula of expansion is

$$Z_1 = z_0 \ La \qquad \text{ohms} \qquad . \quad . \quad . \quad . \quad . \qquad (49)$$

Thus in the case of the cable circuit last considered, if the length be say 1.897 kilometres (1.179 miles); so that $La = 0.1$, the receiving-end impedance to ground becomes $530.4 \ \overline{|44^\circ.39'} \times 0.1 = 53.04 \ \overline{|44^\circ.39'}$ ohms. The correct value by Table XI would be $53.04 \ \underline{|0^\circ.26'}$ as far as two decimal places. The actual conductor-resistance of this length of wire will be in fact $1.897 \times 27.96 = 53.04$ ohms, or this short length of cable wire to ground at the distant end will behave at this frequency, for all practical purposes, as though devoid of inductance and capacity.

To find the current-strength at the sending-end of the grounded line, we may use the right hand side of (30) and obtain:—

$$\mathrm{I} = \frac{\mathrm{E}}{z_0} \coth La = \mathrm{I}_0 \coth La \qquad \text{amperes} \quad . \quad . \qquad (50)$$

This means that when the circuit is shorted at the distant end, the initial outgoing current I_0 is modified by successive reflections in such a manner that in the final state the initial current is multiplied by the hyp. cotangent of the attenuation-length. These values may be found, as far as $La = 1.5$; with the aid of Table IX and Fig. 11. For example, in the cable circuit last considered, if the length be 28.45 kilometres (17.68 miles); so that $La = 1.5 \ \underline{|45^\circ}$ approximately, the hyp. cotangent is $0.883 \ \overline{|11^\circ.42'}$. The initial outgoing current, if an e. m. f. of 10 volts be applied to the circuit, or 5 volts per wire (Fig. 2), will be $\mathrm{I}_0 = \dfrac{5}{530.4 \overline{|44^\circ.39'}}$ $= 0.009{,}427 \ \underline{|44^\circ.39'}$ amperes. The final outgoing current, by (50) will be $0.009{,}427 \ \underline{|44^\circ.39'} \times 0.883 \ \overline{|11^\circ.42'} = 0.008{,}324 \ \underline{|32^\circ.57'}$ amperes. If we analyze this into cophase and quadrature components, we have $\mathrm{I} = 0.006{,}986 + j\, 0.004{,}528$ amperes. The power absorbed by the line will therefore be 0.034,93

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watt per wire expended in I^2R and 0.022,64 watt per wire, elastically oscillating in and out of the dielectric, without waste.

It follows from (50) that the final sending-end impedance of a line grounded at the distant end is

$$z_A = z_0 \tanh La \qquad \text{ohms} \quad . \quad . \quad . \quad . \qquad (51)$$

That is, the initial sending-end impedance is modified, by successive reflections from the distant end, into a final sending-end impedance, through the coefficient tanh La. The values of this quantity as far as $La = 1.5$, and for the imaginary-real ratios 1, 2, 3, 4 and 10, have already been set forth in Table VIII and Fig. 10.

If the attenuation-length be large, as in the case of an electrically very long line, tanh La approaches unity, and

$$z_A = z_0 \qquad \text{ohms} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (52)$$

which is another way of stating that the waves reflected from the distant end of a very long circuit, are inappreciable; so that the initial sending-end impedance remains the final sending-end impedance. Comparing this with formula (43) it is evident that when an alternating-current line is very long, so that the attenuation length La is relatively large, it does not matter whether the distant end be freed, or grounded, or be left in any intermediate condition. The sending-end impedance will be the same. For the case of a cable conductor with an attenuation imaginary-real ratio of 1 very nearly, or an angle of 45° (see Table II) the final sending-end impedance will always be within 1% of the initial sending-end impedance if La be greater than $3 \,\underline{|\, 45^\circ}$. If, however, the imaginary-real ratio be relatively large, as in well-insulated large aerial conductors, La must be made much greater before the change from freeing to grounding the distant end makes only this small difference in the impedance at the sending end.

When, on the other hand, the attenuation-length is so small that its square may be ignored in the formula, we obtain:—

$$z_A = z_0 \, La \qquad \text{ohms} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (53)$$

and the final outgoing current at A becomes

$$I = \frac{E}{z_0 La} = \frac{I_0}{La} \quad \text{amperes} \quad . \quad . \quad . \quad . \quad . \quad . \qquad (54)$$

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By comparing (53) with (49) it is clear that to the degree of approximation considered, the current at the sending and receiving ends of an electrically very short line, with the distant end to ground, will be the same.

At any intermediate point B, Fig. 7, along the line whose end C is to ground, the e. m. f. in the steady state is by (28)

$$e = E \operatorname{cosech} La \sinh L_2a = E \frac{\sinh L_2a}{\sinh La} \quad \text{volts.} \qquad (55)$$

and the current strength at B will also be: =

$$\left.\begin{aligned} i &= \frac{E}{z_0} \operatorname{cosech} La \cosh L_2a \\ &= I_0 \operatorname{cosech} La \cosh L_2a \\ &= i \cosh L_2a \end{aligned}\right\} \text{amperes} \quad . \quad . \qquad (56)$$

The impedance offered at B by the section BC grounded at C, will be, from (55) and (56)

$$z_B = \frac{e}{i} = z_0 \tanh L_2a \quad \text{ohms} \quad . \quad . \quad . \quad . \qquad (57)$$

The ratio of the received current strength at C to the outgoing current strength at A, when C is to ground will be

$$\frac{i}{I} = \operatorname{sech} La \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (58)$$

Similarly the ratio of the received current at C to the current at any intermediate point B, with C grounded is

$$\frac{i}{i} = \operatorname{sech} L_2a \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (59)$$

and the ratio of the final current at B to the current at A, with C grounded is

$$\frac{i}{I} = \frac{\operatorname{sech} La}{\operatorname{sech} L_2a} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \qquad (60)$$

Thus if the cable circuit last considered has an attenuation-length of 1.5 $|\underline{45^\circ}$ and the point B be half-way along the line, so that $L_1a = L_2a = 0.75\ |\underline{45^\circ}$; then by Table VI and Fig. 8, the ratios $\frac{i}{I}$, $\frac{i}{i}$, and $\frac{i}{I}$ become respectively $0.7344\ |\overline{54^\circ.13'}$, $0.975\ |\overline{16^\circ}$, and $0.753\ |\overline{38^\circ.13'}$.

(*To be concluded*).

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ARCHITECTURAL PLATES.

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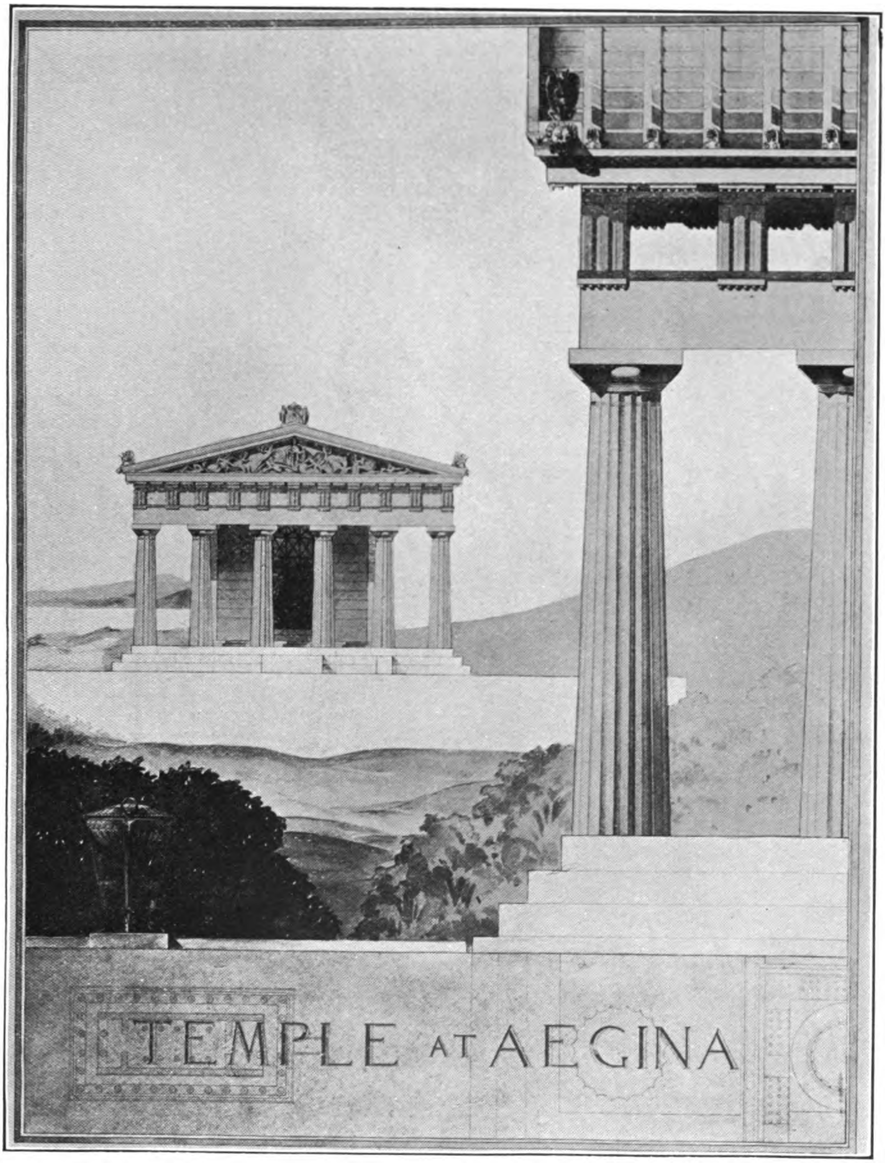

Example of the Doric Order.
C. Everett.

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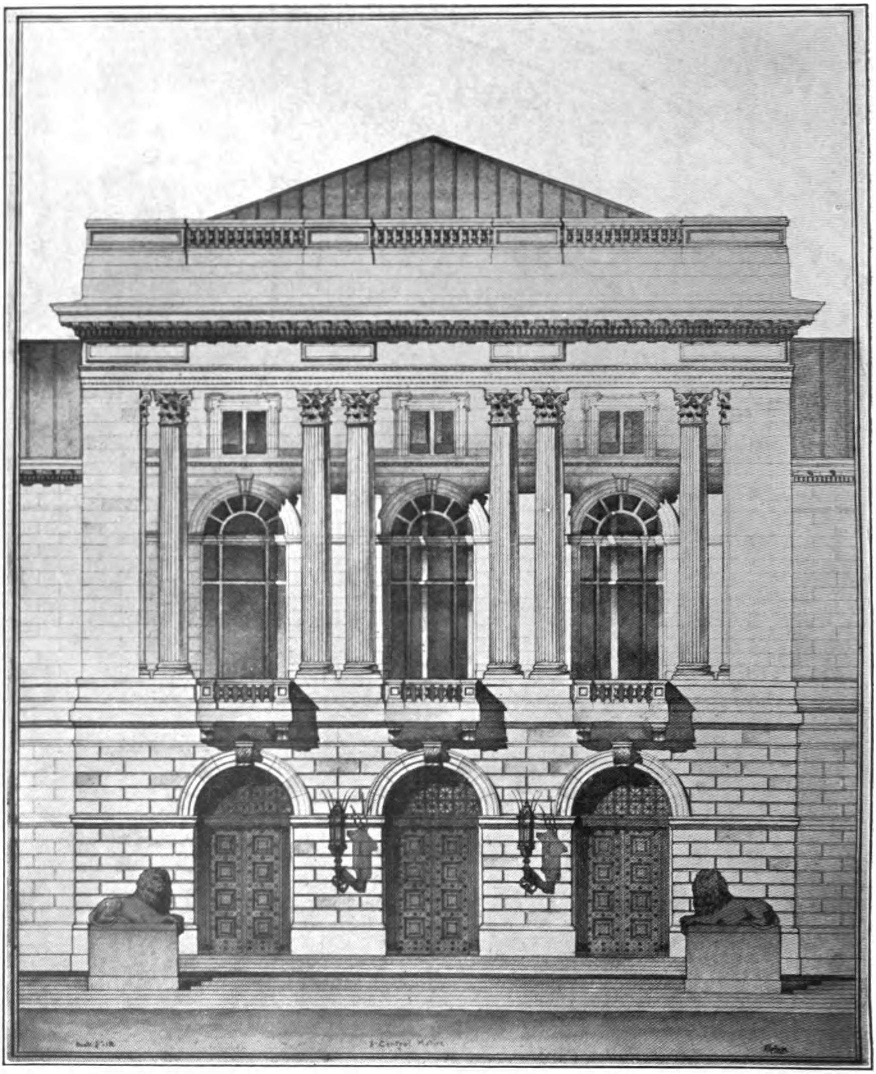

Central Portion of the Facade of a Municipal Building.
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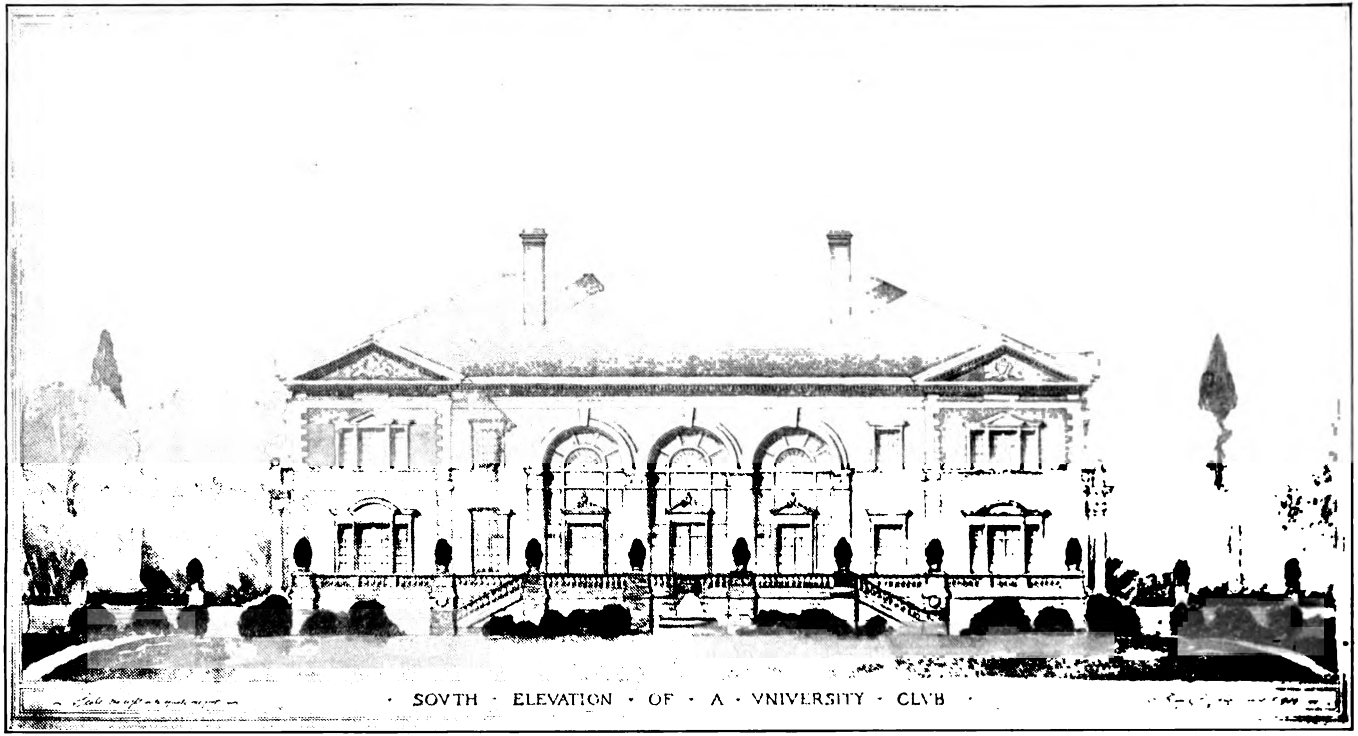

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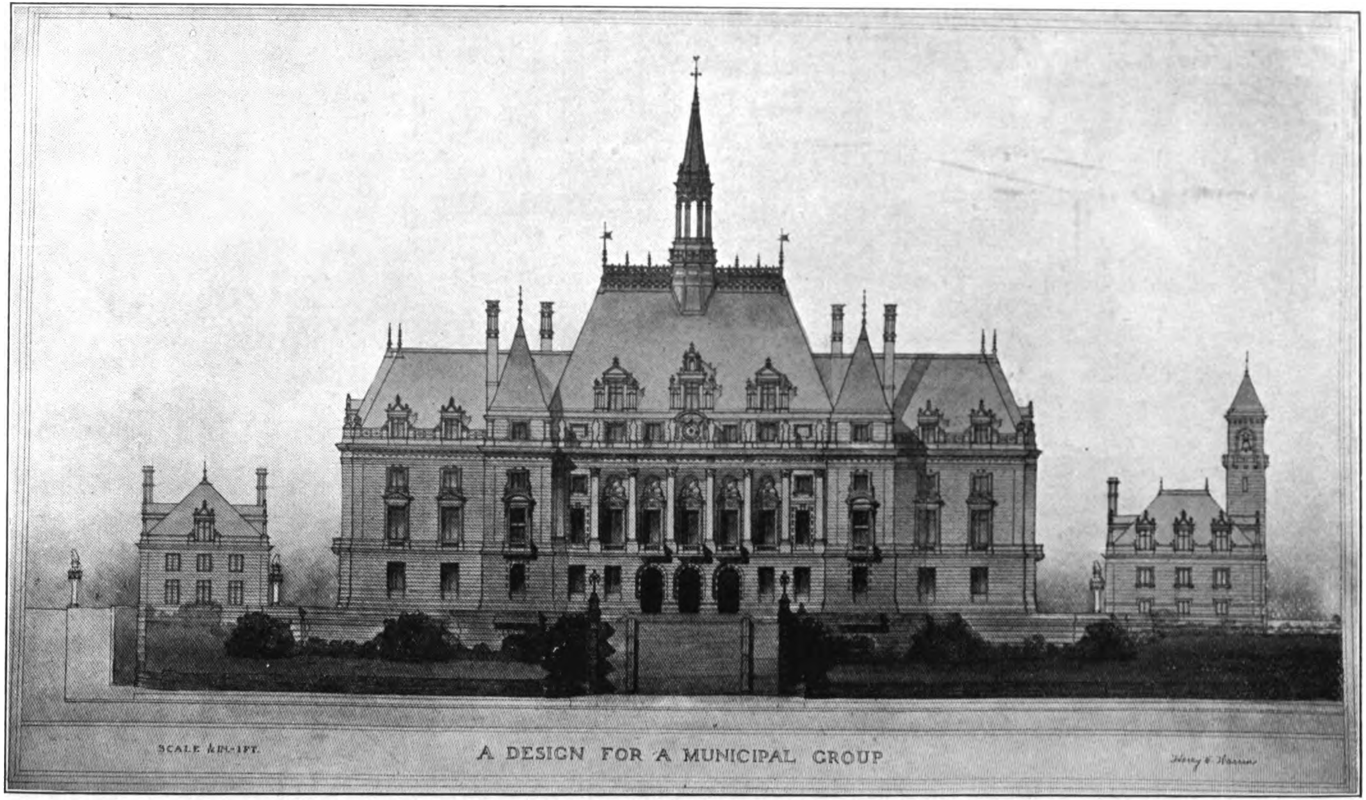

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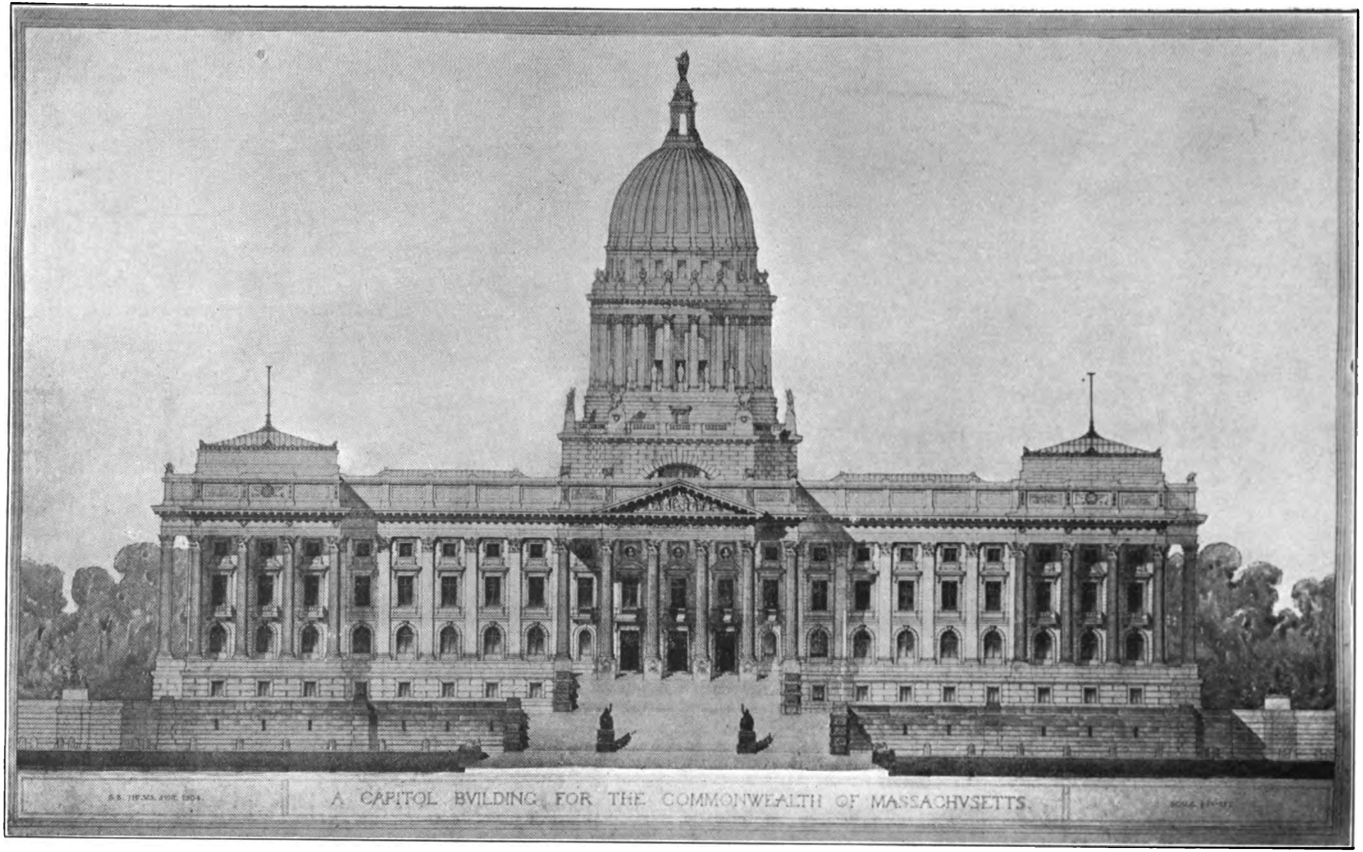

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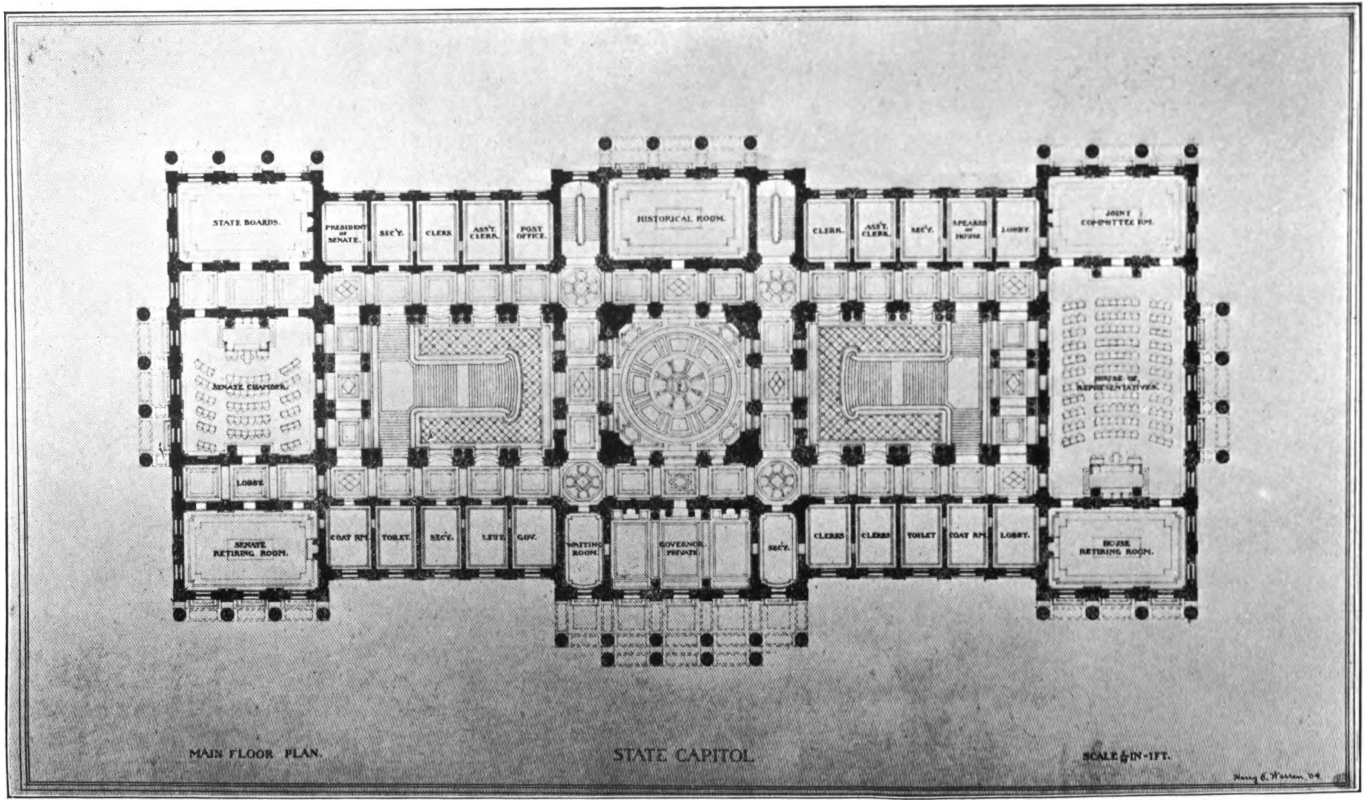

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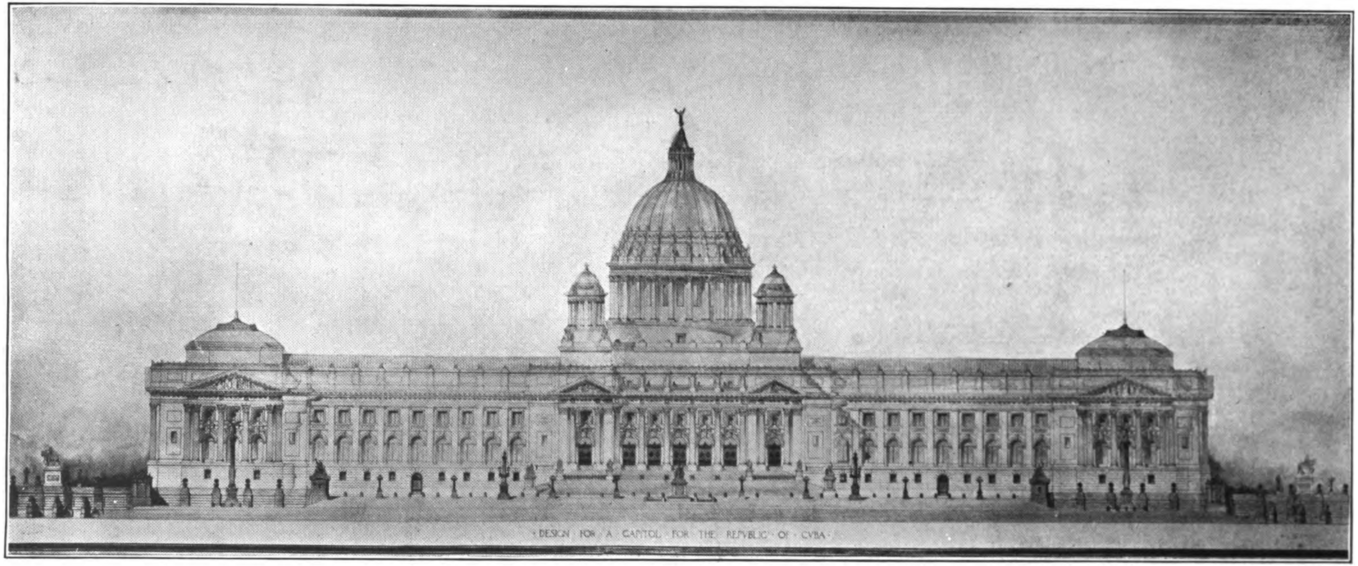

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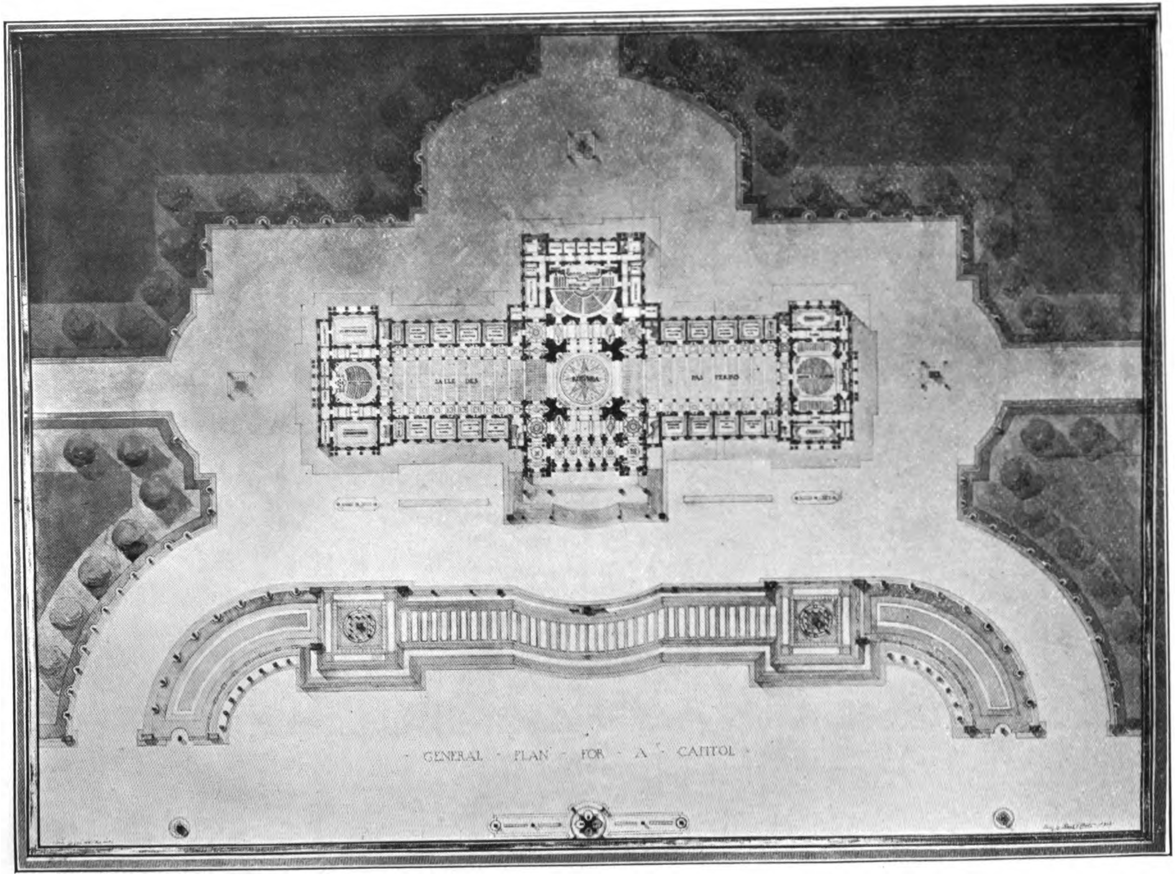

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Editorial.

We take pleasure in announcing the election of the following officers: Wm. Morris Davis 2nd., Sp., as Editor in Chief, Geo. A. McKay, '08, as Business Manager, and Sidney Withington, '07, as Circulation Manager, for the coming year.

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The JOURNAL begins this month the publication of a series of plates illustrative of the work done in the design courses in the architectural department. The four years are represented in the plates chosen for this issue; the order plate done in the freshman year, the municipal facade in the second year, the university club in the third and the municipal group and the two theses in the fourth. There will be published a similar group of plates in succeeding Journals.

HARVARD ENGINEERING SOCIETY.

On Dec. 1, 1905, Dr. S. A. Moss of the General Electric Co. spoke to the Society on "Gas Turbines."

On Dec. 18, Mr. Wm. M. Bailey, Chief Engineer of the Eastern Expanded Metal Co., spoke on "Reinforced Concrete." His lecture was illustrated by lantern slides.

On January 8, 1906, Mr. W. B. Snow of the B. F. Sturtevant Co. gave an illustrated lecture before the Society, describing the construction and equipping of the new Sturtevant plant in Hyde Park.

HARVARD ELECTRICAL CLUB.

The Electrical Club was addressed on December 12 by Mr. R. S. Burbank who spoke on "Electric Lighting in Theatres."

On January 22, Mr. C. H. Hile, the Superintendent of Wires for the Boston Elevated Railway, spoke to the Club on "Power Distribution."

HARVARD MECHANICAL CLUB.

Mr. Winslow Blanchard, Secretary of the Blanchard Machine Co., spoke to the Mechanical Club on December 8. He spoke on "The Graduate of Mechanical Engineering," with particular reference to the problems which confront the young graduate.

Mr. A. Durant, '03, spoke to the Club on January 15. His subject was "The Methods of Locomotive Testing."

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Harvard Mining Club.

On Nov. 9, 1905, in Room 6 of the Union, Dr. E. D. Peters spoke informally on "Experiences in Mexico."

On Dec. 7, 1905, in Training Table Room of Union, Mr. H. Sawyer, Mining Engineer, gave an informal account of "First Experiences in a Western Mining Camp."

On Dec. 21, 1905, the Club attended Mr. Gardner's lecture on the "Siege of Kimberley," Sever Hall.

On Jan. 11, 1906, in the Training Table Room of the Union, Mr. Geo. A. Packard, Mining Engineer, spoke on "Some Peculiarities of our Mining Laws."

Graduate Notes.

Professor W. M. Davis, S. B., '69, M. E., '70, has recently returned from a journey in South Africa, where he went as an invited member of the official party of the British Association. Prof. Davis sailed with the greater number of the party from Southampton, England, July 29; reached Cape Town, August 15, and after a most interesting excursion in the interior as far as Johannesburg, Kimberley and the Victoria Falls of the Zambesi, returned from Beira, a port of Portuguese East Africa, through the Suez canal and the Mediterranean, reaching England about the middle of October. He had an excellent opportunity of seeing the gold mines of the Rand, the coal mines of Vereeniging and the diamond mines of Kimberley. Geological observations were made on various excursions and especial attention was given to the origin of the Dwyka glacial formation, probably of Permian date. All the geologists who saw it agreed that its glacial origin should not be doubted. Prof. Davis gave an account of the Dwyka formation at the New Haven meeting of the National Academy of Sciences, Nov. 14, at the Harvard Geological Conference, Nov. 21, and at the Ottawa meeting of the Geological Society of America, Christmas week.

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L. A. DeBlois, '99, is in California on engineering work in connection with the powder and dynamite companies of the Du Ponts, Wilmington, Delaware. Address: California Powder Co., San Francisco.

C. H. Baker, '02, who was formerly with Allis, Chalmers Co. and for the last three years with Westinghouse, Church, Kerr & Co., New York, is now Inspecting Engineer of Power Houses for the Brooklyn Rapid Transit Co. Address: 85 Clinton St., Brooklyn.

George Ira Alden, '68, is Treasurer and Consulting Engineer of the Norton Emery Wheel Co., and Treasurer and General Manager of the Norton Grinding Co. He was in charge of the Department of Mechanical Engineering of the Worcester Polytechnic Institute from 1868 to 1896. Address: 48 Queen St., Worcester, Mass.

Joseph Gore Cutler, '80, is Chief Engineer of W. & C. R. Railway of the Northern Pacific system. Address: Walla Walla, Washington.

Albert F. Brown, '90, has been employed as Assistant Engineer by the Boston Elevated Railway Co., on the construction of its elevated lines. Address: 36 Maxwell St., Dorchester Center, Mass.

Alvin W. Bancroft, '95, is Superintendent of Wood Department. Heywood Bros. & Wakefield Co. Address: 89 Maple St., Gardner, Mass.

Robert W. Bull, '96, is employed as Electrical Engineer by the New Jersey Zinc Co. Address: Palmerton, Carbon Co., Pa.

Thomas W. Clark, '98, Millinocket, Maine, is Assistant Engineer of Great Northern Paper Co.

Daniel W. A. Armistead, '98, has been with Westinghouse Machine Co., East Pittsburgh, Pa. as Mechanical Engineer on Gas Engine and Steam Turbine work.

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J. M. Boutwell A.B. '97, S.B. '98, S.M. '99, is engaged in studying geology and ore deposits in mining districts in the west for the government. He recently published "Economic Geology of the Bingham Mining District, Utah," professional paper in U.S. G. S. no. 38, and his papers on "Oil and Asphalt Prospects in Salt Lake Valley, Utah," — "Uranium and Vanadium in South Eastern Utah," — and "Ore Deposits of Park City Mining District, Utah," etc., in Bulletin 260 U. S. G. S.

S. C. Cutler, '99, is Vice-President of the Bodifield Belting Co. His address is 24 South Water St., Cleveland, Ohio. His company is in the mill supply business.

Fulton Blake, '99, is with the Submarine Signal Co., his address is 212 Beacon St., Boston.

Henry J. Alexander, '00, is Assistant Engineer in charge of construction work on Section 9 B, New York Rapid Transit Commission. Address : 213 W. 125 St., N. Y.

Nathanial F. Ayer, '00, is assistant treasurer of Farwell Bleaching and Farwell Cotton Mills. Address: 518 Beacon St., Boston.

Julian Dwight Chase, '02, is superintendent, Erecting Department of the B. F. Sturtevant Co. Address: 139 Border St., Dedham, Mass.

Edmund M. Blake, '99, has opened an office at 8 Beacon St., Boston, for the practice of Sanitary, Hydraulic, and Municipal Engineering.

Tileston Chickering, '02, is with Carnegie Steel Co., Pittsburgh, Pa.

J. B. Bancroft, 2nd, '03, is with the Portland Iron & Steel Co., Portland, Me.

Allen G. Chapin, '03, who is correspondent, Railway Department, with the Westinghouse Electric and Manufacturing Co., East Pittsburgh, believes the two year apprenticeship

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course with that company would be very profitable to L. S. S. graduates.

Edward M. Ayer, '03, is Computor to the Gun Division, Army Ordnance Office, Washington, D. C.

Roy Bullen, '05, who entered U. S. Reclamation Service June 29th as Engineering Aid, was sent to the Minidoka Project early in July, where he is assistant to the Engineer in charge of Canal Construction. Address: Rupert, Idaho, via Minidoka.

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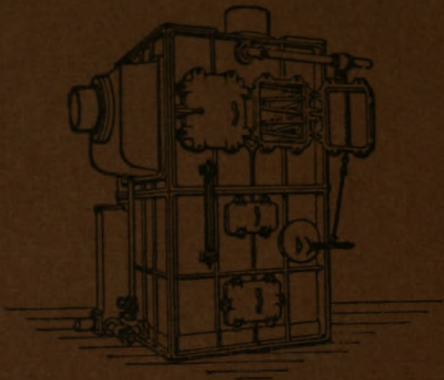

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HARVARD ENGINEERING JOURNAL

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AT HARVARD UNIVERSITY

Vol. V TABLE OF CONTENTS No. 1

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and Architecture at Harvard University

VOL. V — APRIL, 1906 — NO. I

THE PANAMA CANAL UNDER CONTROL OF THE UNITED STATES.

HENRY L. ABBOT,

BRIG. GEN. U. S. ARMY, RETIRED. MEMBER OF THE BOARD OF CONSULTING ENGINEERS.

UNDER the Act approved June 28, 1902, authorizing the construction of the canal the President, after the needful diplomatic and financial preliminaries had been terminated, and acting through an Isthmian Canal Commission of seven members, was charged with the construction of the interoceanic waterway and commodious terminal harbors, and with making provisions for the protection of the same.

This Commission was appointed on February 9, 1904, was confirmed by the Senate on March 3, and held its first meeting on March 22. Its membership was the following, Admiral Walker being its president:

Rear Admiral John G. Walker, U. S. Navy, retired.
Major General George W. Davis, U. S. Army, retired.
William Barclay Parsons, of New York.
William H. Burr, of New York.
Benjamin M. Harrod, of Louisiana.
Carl Ewald Grunsky, of California.
Frank J. Hecker, of Michigan.

Mr. Hecker resigned on November 16, 1904, and his vacancy was not filled.

Legislation for the provisional government of the Canal Zone

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was enacted by Act of Congress approved April 28, 1904. This Zone consists of the land and water contained in a belt ten miles wide extending from a point three marine miles from low water mark in the Caribbean Sea to a like distance in the Pacific Ocean, together with a group of four islands in the Bay of Panama, and such other lands and waters convenient for canal uses as are granted by the treaty with the Republic of Panama. Under this Act the President was charged with vesting the government of the Zone in such person or persons and under such regulations as he might direct. By his letter of instructions of May 9, 1904, the President charged the Isthmian Canal Commission with the government of the Zone as well as with the construction of the canal, both of these duties to be carried on or exercised under the direction of the War Department. General Davis was appointed Governor.

These joint duties of the Commission covered a wide range, to wit: the making of the surveys and investigations and the preparation of the needful plans and specifications; the supervision of the execution of all engineering, hydraulic, and sanitary works required; the enacting of all needful legislation for the government of the Zone, and for the administration of its military, civil, and judicial affairs; the establishment of a civil service based on a merit system; the procurement by purchase or expropriation of all needful lands and, after due advertisement, of all kinds of engineering and construction appliances; and finally the economical and correct disbursement of all canal and administration funds. To these duties would accrue those of directors of the Panama Railroad (the United States having become owner of about 69/70 of its shares) and of its administration in a manner to make it an adjunct to the construction of the canal, and a route of commercial movement across the Isthmus.

The purchase of the property of the New Panama Canal Company having been duly completed, Messrs. Day and Russell, representing the Attorney General of the United States at Paris, instructed Lieut. Mark Brooke, Corps of Engineers, then representing the United States and the Canal Commission upon the Isthmus, to take possession of the property. This was done

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on May 4, 1904. His instructions from the Commission were to continue operations with the employees that had been working under the French Company. This he did until superseded on May 17 by the arrival with full powers of Governor Davis, who continued the work.

Meantime the Commission had devoted its attention to preparations for exercising the extensive jurisdiction confided to its charge. Its first visit to the Isthmus was made on April 5, a month before the transfer of the property, when a study of the French operations and current methods of work was made; and further examinations at Colon, Gatun, Bohio, and the Upper Chagres valley, in connection with ultimate plans for the canal, were projected and were inaugurated in May. Colonel Gorgas and other medical experts accompanied the Commission at this visit, and were thus prepared to begin to organize an efficient health department at the very outset of the work.

For the performance of its multifarious duties the Commission divided itself into six committees,— one on engineering plans, one for executive work, one on engineering, one on finance, one on legislation, and one on sanitation. The chairman of the Commission was *ex officio* a member of each committee, as was also General Davis, Governor of the Zone, when meetings were held on the Isthmus.

The most pressing duty of the Commission was to establish a classified organization on the Isthmus suited to deal with problems involving accounting, material on hand, machinery, supplies, recruiting of labor, etc. Then followed the political conditions of the Zone government. This latter demanded a degree of attention which may be estimated from the fact that between August 16, 1904, and March 1, 1905, twenty-four laws were enacted "by authority of the President of the United States" covering: organization of a judiciary, notaries public, suppression of lotteries, prohibition of gambling, temporary alcaldes, expropriation, municipal governments, executive branch, sanitary regulations, quarantine regulations, legal holidays, penitentiary, officers of courts, penal code (18 titles), criminal procedure (15 titles), salaries of certain officers, administration of certain estates, and seven Acts

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amendatory of above. These Acts cover 136 octavo pages of small type in the two annual reports.

The Panama Railroad administration involved other difficult problems for the Commission. Being a Company chartered (in 1849) by the State of New York it was legally necessary to administer it through a board of directors; and this had caused the nomination of the members of the Commission to represent the shares owned by the Government. The outstanding shares were promptly acquired by purchase, but in the absence of special legislation by Congress this administration through a board of directors is still obligatory. When the ownership passed to the Government the transit route consisted of 47.65 miles of single track road between Colon and Panama, with 26.07 miles of sidings; the road bed was in good condition but considerable repairs were needed both in track and equipment. Much land and many buildings were also owned by the Company, together with a line of steamers running to New York, but the dockage facilities were altogether inadequate for the new demands. The management of the road both as a route of commercial transit between oceans, and as a vital agency in the construction of the canal, imposed complex problems upon the Commission.

Mr. John F. Wallace was elected Chief Engineer by the Commission on May 6, 1904, and was duly appointed under date of June 14, to take effect on June 1. He arrived on the Isthmus on June 28, accompanied by Colonel Gorgas charged with the sanitary administration.

Mr. Wallace found a few hundred men at work on the Culebra cut under Major William M. Black of the Corps of Engineers; and, in progress of execution, the technical investigations ordered by the Commission at Colon, Gatun, Bohio and on the Upper Chagres. He directed his attention to continuing these works and, in succession, to the organization of his staff; to the repair of the old buildings and the erection of new; to the water supply and sewerage problems; and to making requisitions for steam shovels and other important supplies. Later, on April 1, 1905, he was duly elected vice-president and general manager of the Panama Railroad, having performed the latter duties for some

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weeks, under protest at occupying a subordinate position. Indeed from his testimony before the Senate Committee on Interoceanic Canals it appears that from the outset he chafed vigorously against supervision in his canal duties, and at the delays inherent to the inauguration of governmental operations so far removed from the base of supplies. Most of his previous experience had been with railroad methods.

It will be noted that the only work involving actual construction of the canal has been carried on at the Culebra cut where, with a view to secure data for estimating the unit cost of excavation, operations on a small scale were conducted with the French excavators and appliances during the last six months of 1904. The latter were gradually replaced with American steam shovels, the first being installed on November 11, 1904, and the last excavator being discarded on June 16, 1905. Early in August, 1905, when 11 steam shovels had been put at work, the necessity of using the laboring force elsewhere in preparatory operations caused this experimental work gradually to cease. The cost per cubic yard in place, computed upon the basis of outlay to a contractor, is shown in the following table.

Month.	Output in Yards.	Cents per Yard.
July, 1904.	31,599	64.5
August	35,056	50.2
Sept.	25,220	55.9
Oct.	19,695	52.5
Nov.	28,860	47.4
Dec.	42,935	50.1
Jan., 1905.	70,650	47.8
Feb.	75,200	46.5
March	132,840	43.3
April	126,749	52.5
May	75,935	83.8
June	76,905	102.7
July	78,570	103.5
August	49,210	153.9
Sept.	41,885	144.1

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In considering this table it is to be noted that the decision of the Attorney General, taking effect on June 1, 1905, that the eight hour law extended to the Isthmus (shortening the hours of labor 20 per cent without reduction of pay), together with the use of different plant at different dates and, what is still more vital, the fact that the excavation had not reached a depth to develop fully the difficulties and delays resulting from unavoidably having to transport the spoil to distant dumps, tend largely to deprive the resulting unit prices of any safe application except perhaps to a lock canal of high summit level. The estimate of the Comité Technique, based on the actual cost of removing much larger volumes, varied from 52 to 81 cents according to the material encountered in the cut; that of the Isthmian Canal Commission of 1899–01 was fixed at 80 cents. If these new data prove anything they must be regarded simply as confirmatory of those previous valuations of probable cost, neither of which contemplated excavation below that corresponding to a summit level of 65 feet above mean tide.

From the outset Mr. Wallace had shown a strong bias in favor of reviving the old project of M. de Lesseps for a sea level canal, although after the disastrous failure of 1889 it had been rejected by every French and American commission that had technically studied the subject. In November, 1904, at a hearing before a Congressional Committee held in Colon harbor, he made suggestive references to it; and finally in his report of February 1, 1905, he announced, upon the basis of the above experimental excavations at the Culebra, or rather those of them terminating before the date of his report: "The Chief Engineer feels warranted in recommending 50 cents per cubic yard as the unit price for this central section for estimating purposes. He is also satisfied that each excavating unit, after the necessary track systems are properly installed and the organization perfected, will produce an average output of 1000 cubic yards per machine per single daily shift, and that this average can be continuously maintained, yielding an output of 300,000 yards per annum per machine * * * It would not be wise to make calculations on an excess of 100 machines continuously at work. This would yield an output of 30,000,000

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yards per annum. On the sea level plan there are, in round numbers, 186,000,000 cubic yards of material in the Culebra division, which would require on the above basis six years to excavate. Allowing two years for preparation and two years in addition for contingencies and unforeseen delays, it would seem evident that it would be possible to complete the canal or at least open it for use in ten years, certainly in twelve."

The engineering committee of the Commission, at a meeting held on the Isthmus in February, 1905, at which Messrs. Burr, Parsons and Davis were present, having this report before it, recommended the adoption of a sea level plan for the canal, with a bottom width of 150 feet, and a minimum depth of water of 35 feet, and with twin tidal locks at Miraflores whose usable dimensions should be 1000 feet long and 100 feet wide; the estimated cost being $230,500,000. The plan included a dam at Gamboa built to a crest height of about 200 feet. It was recommended that this dam be undertaken at once and completed as soon as practicable. The plan would "probably require a masonry core, with a large mass of earth and rock fill on either side of it, from the waste excavation of the summit cut * * * The necessary rates of the outflow from the lake during flood periods may be obtained by means of large pipes and gates built into the dam itself, together with a waste weir at the same point, or by means of a tunnel about 3.4 miles long through the dividing ridge between the Chagres and Gatuncillo watersheds, or by both." This report of the committee was laid before the Commission at its 80th meeting, on February 23, 1905. It was considered at the 84th and 86th meetings, when it was referred to the committee on engineering plans for consideration and comment. No further action appears to have been taken thereon.

It appearing in the autumn of 1904 that the people of the Republic of Panama were alarmed at some of the legislation of the Commission relative to the government of the Zone, which they feared would reduce their revenue and affect business at Panama by imposing United States duties at the Zone port of Ancon (La Boca), the President on October 18 requested the Secretary of War to visit the Isthmus and hold a conference with

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the governmental authorities of the Republic. This mission was successfully accomplished, resulting in the issue by Secretary Taft of two executive orders which regulated the matters in question upon a basis satisfactory to all parties concerned.

Reorganization of the Commission.

An order of the President dated April 1, 1905, announced in its first paragraph: "The practical result of the operations of the Isthmian Canal Commission appointed and acting under previous executive orders has not been satisfactory, and requires a change in the personnel of the Commission and in the instructions for its guidance."

The new instructions may be briefly summed up as follows:

The Commission to hold quarterly stated sessions upon the Isthmus continuing as long as public business may require, and also special sessions at the call of the chairman; four members to constitute a quorum.

An executive committee of not less than three members, to represent the Commission during the intervals between the stated sessions, to hold regular meetings at the office of the Governor at 10 A. M. on each Monday and Wednesday, a majority of the members constituting a quorum. Minutes of every transaction to be kept and transmitted to the Secretary of War and to the Commission.

Under the supervision and direction of the Secretary of War, and subject to the approval of the President, the Commission to be charged with adopting plans for the construction and maintenance of the canal; with the purchase and delivery of supplies and plant; with the employment of officers, employees and laborers, including the fixing of their compensation; with the commercial operation of the Panama Railroad and its steamship lines; with the utilization of the railroad for constructing the canal; with the making of contracts for the constructions and excavations, and with all other matters incident to the building of a waterway across the Isthmus.

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The head of the first department (the chairman of the Commission) to have direct and immediate charge of the fiscal affairs; of the purchase and delivery of materials and supplies; of accounts, bookkeeping and audits; of commercial operations of the Panama Railroad and its steamship lines, in the United States; of the general concerns of the Commission, and of such other duties as may be placed on him by the Secretary of War under whose supervision and direction he shall act.

The head of the second department (the Governor of the Zone) to continue to perform the duties heretofore prescribed, including the administration and enforcement of law; all matters of sanitation within the Zone, and in the cities of Panama and Colon and in the harbors so far as now authorized; the custody of all sanitary supplies, and such sanitary constructions as may be assigned by the Commission; and such other duties as may be devolved on him by the Secretary of War. He shall reside on the Isthmus.

The head of the third department (the Chief Engineer) to have full charge on the Isthmus of actual work of construction; the custody of all supplies and plant; the practical operation of the Railroad in view to its utilization in construction. He shall reside on the Isthmus.

Officers and employees to be appointed, and their salaries fixed, by the head of the department in which they are engaged, the compensation being subject to the approval of the Commission or executive committee. Laborers hired outside the Isthmus to be engaged by the chairman subject to approval by the executive committee; upon the Isthmus this to be done by the Chief Engineer subject to approval by the executive committee.

Contracts for supplies or construction involving an expenditure exceeding $10,000 to be made only after due public advertisement, and to be awarded to the lowest responsible bidder, except in case of emergency when with the approval of the Secretary of War advertising may be dispensed with. Contracts involving more than $1000 or less than $10,000 should be based on competitive bids secured by invitation or advertisement whenever practicable.

The reorganized Commission to assemble in Washington for the general purpose of reorganization and for the special purpose

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of fixing the number and character of officers and employees to serve in Washington. A complete system of accounts to be maintained on the Isthmus and duplicated in Washington, so that the amount of work done, its cost, the amount of money available, the amount expended, and the general financial condition of the enterprise may at any time be reported.

The executive officers of the Commission to make duplicate reports upon the operation of their respective departments to the Secretary of War and to the chairman of the Commission, as often as may be required; and the Secretary to make a report at least annually to the President, and oftener if required.

A board of consulting engineers having experience in works of canal construction and hydraulics will hereafter be appointed; to which will be submitted by the Commission, for its consideration and advice, the important engineering questions arising in the selection of the best plan for the construction of the canal. Its recommendation after consideration by the Commission, and with its recommendation, to be finally submitted through the Secretary of War to the President for his decision.

The membership of the Commission appointed by this order to be:

Theodore P. Shonts, chairman.
Charles E. Magoon, governor of the Canal Zone.
John F. Wallace, chief engineer.
Rear-Admiral Mordecai T. Endicott, U. S. Navy.
Brig. Gen. Peter C. Hains, U. S. Army, retired.
Col. Oswald H. Ernst, Corps of Engineers U. S. A.
Benjamin M. Harrod.

The Commission reconstituted under this executive order held its first meeting on April 3, 1905. Mr. Wallace tendered his resignation as Chief Engineer on June 28, and his connection with the Commission was then terminated by the President in a letter dated the same day. The vacancy of Chief Engineer was filled on July 1 by the appointment of Mr. John F. Stevens; but as he was not made a member of the Commission or of the executive committee, the direct jurisdiction of the chairman was extended over the third department. Mr. Stevens arrived on the Isthmus on July 26, 1905.

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Under date of June 24, 1905, the President issued an executive order appointing the board of consulting engineers, which finally was thus constituted:

George W. Davis, Major-General U. S. Army, retired, Chairman.

Alfred Noble, Chief Engineer East River Div. P. N. Y. and L. I. Railroad.

William Barclay Parsons, Chief Engineer New York Subway.

William H. Burr, Consulting Engineer Board of Water Supply New York City; Prof. Civil Engineering, Columbia University; Eng. Expert of Aqueduct Commissioners, New York City.

Henry L. Abbot, Brig. Gen. U. S. Army, retired.

Frederic P. Stearns, Chief Engr. Metropolitan Water & Sewerage Board, Boston.

Joseph Ripley, Gen. Supt. St. Marys Falls Canal.

Isham Randolph, Chief Engineer Sanitary District of Chicago.

William Henry Hunter, Mem. Inst. C. E. Chief Engr. Manchester Ship Canal; Commissioner, Upper Mersey Navigation, England.

Eugen Tincauzer, Königlich Preussischer Regierungs und Baurat, Mitglied der Regierung zu Königsberg i. Pr., Germany.

Adolphe Guérard, Inspecteur Général des Ponts et Chaussées, France.

E. Quellennec, Ingénieur en Chef des Ponts et Chaussées; Ingénieur Conseil de la Cie. du Canal de Suez, France.

J. W. Welcker, Hoofdingenieur Directeur van den Ryks Waterstaat, The Netherlands.

Captain John C. Oakes, Corps of Engineers, General Staff, U. S. Army, was detailed as Secretary of the Board.

This Board was instructed by the President to assemble at Washington, D. C., on September 1, 1905, "for the purpose of considering the various plans proposed to and by the Isthmian Canal Commission for the construction of a canal across the Isthmus of Panama between Cristobal and La Boca"; their deliberations to "continue as long as they may deem it necessary and wise, before they make their final report to the Commission"; the Commission to have the plans ready in sufficient detail to enable

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the Board "to consider and decide the questions presented to them"; and the Board to visit the Isthmus should they deem it necessary before making their final report. Should a difference of opinion arise, "minority reports are requested."

The Board assembled as directed; sailed from New York for the Isthmus on September 28, and arrived back on October 17, having made a careful inspection of the route of the canal, receiving detailed information from the engineers and other officials as to the latest developments. They suggested certain further examinations which were promptly made by the Commission. After an exhaustive study of the ample data presented, the Board reached its final conclusions about the end of November, and the European members returned to their homes. An irreconcilable difference of opinion had developed. Eight members, including the five from Europe and the three who had formed the Engineering Committee of the late Isthmian Canal Commission, favored a sea level project somewhat upon the lines which the latter had reported in February, 1905, but with important modifications; the other five members of the Board favored a lock canal with a summit level 85 feet above mean tide, formed by a dam at Gatun, thus in large measure substituting lake navigation for a relatively contracted waterway. When the drafting of the majority report was completed it was taken by General Davis to Europe and was there signed by the European members; meantime the minority report was drafted and signed in New York. Together with numerous appendices, maps and drawings they were presented to the Commission early in February, 1906; and on February 19, were transmitted by the President to Congress together with his own views, and those of Secretary Taft, and of the Commission, and of Chief Engineer Stevens, — all substantially indorsing the lock canal project presented by the minority of the Board of Consulting Engineers. It seems therefore hardly doubtful that Congress will soon authorize the immediate prosecution of the work on these general lines, which essentially conform to the recommendations of every commission of engineers which has officially studied the subject since the fiasco of M. de Lesseps.

Of late the press has teemed with groundless vituperation against

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the conduct of operations on the Isthmus, forgetful that a period of preparation must precede active prosecution in a work of this magnitude so far removed from the base of supplies. A large working force (22,000 including canal and railroad employees) has been assembled and comfortably established; extensive sanitary provisions have been made with untiring energy to minimize the danger of serious sickness in an inhospitable climate,— resulting in a death rate ranging from only 30 to 40 per 1000; an efficient plant is rapidly collecting; and the question of plan appears likely soon to be solved. It would be most unreasonable to expect more in the few months which have elapsed since the work passed under the control of the United States.

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TRAIN RESISTANCE.

BY C. O. MAILLOUX.

(Continued from the April, 1905, Issue).

Composite Friction. (Combining sliding and rolling friction.)

There are certain elements of train resistance which, apparently, involve and result from both sliding friction and rolling friction.

The characteristic outward indications or symptoms of this "composite" friction are certain erratic irregular movements of the car attended by vibrations, jolts, shocks, swaying, rocking, etc.

The immediate "cause" is a variation or fluctuation, more or less sudden and marked, in the *amount* of pressure exerted by the wheels *individually*, upon the rails, and also a variation or fluctuation in the *direction* in which this pressure acts.

The primary cause is either want of uniformity in the *gauge* ("alignment") of the track, or inequality in the *elevation* of the two rails at the same part of the track. This lack of uniformity is ascribable, in part, to defects in the rails themselves, resulting from improper straightening or bending, and to defects in the rail joints; and, also, in part, sometimes mostly, to track curvature, to unequal and non-uniform yielding of the ties, ballast, subgrades, etc. Whatever may be the cause, the "effect" is a lateral displacement of the car-wheels, as they pass over the various inequalities in question, and a corresponding more or less sudden and forcible thrust of the wheel-flanges against the inner side of the rail-head.

The lateral pressure of a car-wheel flange against the inner side of a rail-head not only tends to force that rail outwardly, (or away from the center of the track), but it also, at the same time, tends to make the wheel ride or roll over the "fillet" of the flange or that portion of the "coned" tread which is of the largest diameter, and which is near the inner side of the rail-head. The rail-head

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is subjected, in consequence, to a ***resultant pressure***, of which the two components are:—

(a) The lateral pressure due to the side "thrust", and,

(b) The vertical pressure due to the weight of wheel, car, etc.

This resultant pressure has a direction such that the pressure exerted against the rail is a maximum at the inner, upper edge of the rail-head. The pressure-density, while increasing, at this portion, has decreased at the outer portion of the rail-head (Figs. 12 and 12a). The greater the force due to the side thrust, the more the resultant pressure (while it is increasing) becomes concentrated on the inner upper edge of the rail-head. The pressure-density may increase owing, (1st) to actual increase in pressure, (2d) to decrease in contact area. If, as sometimes happens, the pressure-density attains and exceeds the elastic limit of the metal of the wheel-tread, or of the rail-head, the metal will be "disturbed" or "upset," and there will occur a certain amount of permanent change or "set" in it, by the agency of *rolling* friction. When there is no "slipping" between the surfaces in rolling contact, the metal which "yields" because of a pressure-density exceeding its elastic limit, is partly *carried* along in the direction of the motion and at the same time partly spread out sidewise by the rolling action; and it is then said to be "cold-rolled." The "mashing" of the rail-heads at frogs and switches, and the "scales" found on the rail-head, or the "slivers" found occasionally, at the side of the

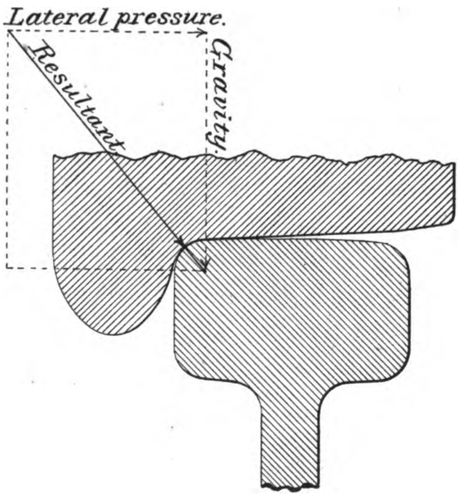

FIG. 12.

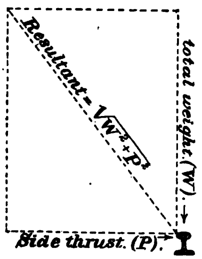

FIG. 12a.

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rail-head, are results and evidences of this "cold rolling" action. When there is some "slip" between the rolling surfaces, the action is complicated by the presence of pure sliding (unlubricated) friction. This condition arises and is well illustrated, when the wheel-flanges are forced against the inner side of the rail-head on one side of the track. The wheels then rest on different portions of their coned tread, on the two sides, and some slipping will occur in consequence of the difference in the *effective* peripheries of the two wheels mounted on the same axle. This slipping causes much local variation in the pressure-density and, consequently, much inequality in the "yielding" of the weaker metal, some particles of which are partly torn away bodily, or ground off (abraded), while the others are "upset" or else "cold rolled," as in the previous case.

A B—(1). *Effects of Concussion and Oscillation.*

The term "concussion" may be applied to all impulsive movements of a car which produce jolts, jerks, shocks and other unpleasant sensations, as the result of "lost motion," due to "play," in certain parts of the car, more especially at the car-couplings and at the axle-journals and wheel-flanges.

These movements themselves may be regarded as the "resultants" of *component motions* occurring in three planes, one vertical, one horizontal, which are both *parallel* to the track, and one vertical which is *perpendicular* to the track.

The concussion attending these movements is of two kinds:—"End" concussion, and "side" concussion.

(a) The "end" concussion, due mostly to the "lost motion" allowed by the "play" in the couplings between the cars, is made manifest by the succession of "bumping" blows occurring at the couplings, in a long freight train which is starting or stopping. It also occurs, though it is less marked, in passenger trains, not only when starting and stopping, but at all speeds. The motion producing this kind of concussion is, obviously, parallel with the track. It may be and it usually is, complicated by some "up-and-down" or "side-to-side" motions of the car, constituting *oscillations*, in planes, horizontal, vertical, or resultant, which are substantially parallel with the track.

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(b) The "side" concussion, which is due to the lost motion allowed by the end-play of the car-axles and by the play between the wheel-flanges and the track (*i. e.* the rail-heads), corresponds to the lateral displacements of the car-trucks, or of the car-body, or of both, first to one side, then to the other, in more or less rapid and irregular succession, constituting *oscillations* in a *horizontal* plane. These oscillations may involve only the car-trucks, or only the car-bodies, or both of them.

(c) The "rocking" of a car, from side to side, or its oscillation in a vertical plane transverse to the track, may have, theoretically, some relation to "side" concussion; but, practically, while it represents oscillations which are superposed upon and which complicate the other oscillations, its effect on train resistance is of minor importance, and is probably negligible, for cars having good springs, at all ordinary speeds.

Concussion and oscillation (of the first two kinds mentioned) are found occurring together so generally, that they may be regarded as concomitant phenomena. Indeed, the relation between these two phenomena is so intimate that it proves difficult, in most cases, to determine which of the two follows, or results from, the other.

Apparently, either may cause or lead to the other. Vertical oscillation, such as, for instance, that resulting from localized depressions or yielding of *both sides* of the track, under a moving train, may cause "end"-concussion; and end-concussion, resulting from abrupt changes of velocity, however produced, may cause vertical oscillations. A localized depression or yielding on *one side only* of the track may cause the car to swing (oscillate) to that side, until side-concussion results, by end-thrust at the axle-ends; and this may, in turn, cause one or more wheel-flanges to be forced against the rail-heads, on the same side, again producing side-concussion and, at the same time, facilitating the production of an oscillation of the car-truck itself; in which case, the concussion will occur at both sides of the track. The process is obviously reversible; and the oscillation of a car-truck, from any cause, can bring about the oscillation of the car, the production of end-thrust, concussion at the axles, etc.

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It soon becomes evident, when we consider the energy transformations involved, that the reciprocal relations just noted between concussion and oscillation constitute a very important means, indeed, the principal means, of transfer, as well as of conversion, of the energy involved in concussion. We know that the energy which is converted into heat by concussion, in this case, must have been abstracted from the energy which is available and which serves for moving the car or train. It must, therefore, have a "force-factor," or a horizontal component, which constitutes a *part* of the total "tractive effort" or "tractive force" acting to move the car or train. It is not difficult to see that the oscillations which we have noted, enable the *mass* of the *car*, trucks, wheels, etc., to play an important role in "storing" and "restoring" the energy involved in concussion. The dynamic reactions involved are closely analogous to those observed in the case of the rolling friction due to an "intermittent obstruction." There is an instantaneous increase in the "demand" for energy, in consequence of the concussion. This demand is satisfied by a supply derived from the nearest and readiest source, viz., the potential or the kinetic energy in the mass of the car, trucks, or wheels. This mass, by change either of *position* or of motion (*i. e.* by its *weight* or by its *momentum*), may furnish, provisionally, the whole or a part of the extra supply of energy required. The "restoration" of this energy to the mass, is effected, subsequently, by the agency of the force applied to the car; and this restoration involves, obviously, a reversal of the change of "position" or of "motion" just mentioned, or a motion which is the counterpart of that by which the mass energy was "given up." Each oscillation is, therefore, in a dynamic sense, a step or an "incident" of some energy compensation or adjustment; it is a detail, so to speak, of a process or operation whereby, during a concussion, the mass of the car, truck, wheels, etc., "gives" or "takes" energy momentarily, enough to maintain a "balance" between the energy "consumed" and the energy "applied."

The energy expended in compressing car-springs or any other elastic parts, during an oscillation is, at least theoretically, recoverable. (It is for this reason that the "rocking" of a car does

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not materially increase train resistance, when the rocking is not attended by concussion, in some way). The "force-factor" of the train resistance due to concussion includes only the horizontal component of that portion of the concussion energy which is converted into heat, directly or indirectly, as the result of the concussion, and also that which is expended in producing non-reversible physical effects, such as cold-rolling, grinding, indentations, or like effects characteristic of rolling friction, in the rail-heads, wheel-treads, axles, couplings, bumpers, or other parts exposed to the blows or shocks.

It is apparent from the preceding considerations, that the train resistance due to concussion must depend upon the *number* and the *character* of the oscillations attended by shocks, which occur in a given time. As might be expected, it is decreased by all conditions conducive and favorable to smooth and steady running, being lowest on tracks of the highest "quality" in respect to rigidity of rail, stiffness of joints, perfection of alignment, surfacing, etc. Next in importance to the quality of the track is the length of wheel-base. The longer the wheel-base, the fewer the oscillations of the truck and the fewer the number of hits of the wheel-flanges against the rail-head. It is believed that rigid trucks have some advantage over pivoted trucks in this respect, as they seem to have, also, in regard to wheel-flange friction, on a straight track.

It has been observed, in the case of long trains, that the forward cars are the most free, and the rear cars the least free, from oscillation and concussion. This difference is ascribed to the steadying effect of the tension ("drag") due to the tractive force transmitted to the rear cars, through the car-couplings and the car-bodies of the forward cars. This tension is, obviously, a maximum at the first car-coupling, where it is equal to the total draw-bar pull, and it is a minimum at the last coupling, where it is equal to the tractive force required for the last car only. In ascending a grade, the tension at each coupling and the total draw-bar pull are increased in proportion with the steepness of the grade; and, as might be expected, the steadying effect is found to be increased also, and the amount of concussion (and also of flange-friction) is found to be reduced. In descending a grade, the tension will be

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diminished and the amount of oscillation and concussion (also of flange-friction) will be increased.

The fact of a relative decrease in train resistance in ascending grades and of a relative increase thereof in descending grades was confirmed many years ago, by a French railway engineer, M. Barbier, by the results of elaborate dynamometric tests. The true cause of this difference was not apparently understood by this observer, who ascribed the difference to some unexplained discrepancy (amounting to about 10 percent) between the "theoretical" and "practical" effects of grades. He proposed the coefficient 0.9, which became known as "Barbier's coefficient." There are no data relative to the value of this coefficient for other cars and conditions than those referred to by M. Barbier. The value would probably be different with American cars, which have pivoted instead of rigid trucks, and would probably differ with the kind and especially the length of car.

Authorities are not in agreement regarding the influence of velocity on the train resistance due to the effect of oscillation and concussion. It is generally believed or assumed to increase with the train velocity. According to Wellington, this resistance may be estimated at 0.5 lb. per ton, at a velocity of 10 m. p. h. and it increases as the *square* of the velocity. In nearly all formulæ, this resistance is assumed to be a function of the square of the velocity. This assumption may not be fully warranted.

The data at present available, as the result of tests and observations, are too meagre to enable this portion of train resistance to be "segregated" completely and satisfactorily from the other portions and to enable its functional nature and its "constants" to be exactly determined.

A B — (2). *Effects of Curves.*

It has been known, practically from the beginning of the art of railroading:— first, that additional tractive force is required to move cars on curves; second, that lubrication of the rails, especially at the inner side of the rail-head, on curves, has the effect of greatly diminishing the "curve resistance."

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When a car is going around a curve, on a railroad track, the wheel-flanges are brought into more or less forcible contact with the rail-heads, on one or both sides of the track, causing both sliding and rolling friction against the sides and inner upper edge of the rail-heads. The conditions are, however, materially different from those attending the oscillations of a car-truck on a straight track. While rolling friction is the principal factor of the increase in train resistance due to the effects of oscillation and concussion, sliding friction is the principal factor of the increase in train resistance due to track-curvature. While the flange-contact due to truck oscillation is more or less "intermittent" and brief in duration, the flange-contact due to track-curvature is more or less "persistent"; it remains substantially continuous until the curve has been passed. The length of the wheel-base also has an exactly opposite effect, in the two cases. Its increase, which has the effect, on a straight track, of decreasing the number of truck oscillations, has the effect, on a curved track, of increasing the wheel-flange friction. For a given wheel-base, the extra resistance due to a curve will increase with the "sharpness" of the curve.

While the frictional effect, itself, which is produced between the flange and the rail, on a track curve is similar in character to that resulting from oscillation of the car-truck, on a straight track, there is a material difference in the manner in which the wheel-flanges are brought into contact against the rail-heads. The *oscillation* of the car-truck, on a *straight* track, causes the contact between the wheel-flanges and the rail-head to be shifted *ahead* of the vertical diameter of the wheel, on one side of the track, (*i. e.* the side *toward* which the truck turns), and *behind* this vertical diameter, on the other side of the track. The *distance between* the flange-*contacts* is the same for both sides, being always substantially equal to the wheel-base. In the case of a car-truck which is moving *around a curve*, the mode and kind of contact between the wheel-flanges and the rail-heads will vary greatly, being especially influenced by the "sharpness" of the curve, and the "length" of the wheel-base. When the curve is very sharp, or when the wheel-base is relatively long, (as in the case of a single-

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truck street car, or in the case of European "rigid-truck" cars), the flange-contacts occur in such manner that the distance between the two is *less* than the wheel-base at the inside rail, and *greater* than the wheel-base at the *outside* rail. See Fig. 13.

Under these "extreme" conditions, which are, too often, the "normal" and prevailing conditions, in street railway practice, no wheel-flange can "escape" contact with the rail-head, because the truck has no "freedom" of position. Flange friction occurs at all the wheels, and the curve-resistance is a maximum. It may be reduced slightly by widening the gauge of the track at the curve.

Under more favorable conditions, the flange-friction does not usually occur at all the wheels of the truck. The shorter wheel-base found in cars equipped with pivoted trucks allows the trucks and the wheels more freedom of position with reference to the track. It was found, by Wellington, as the result of experiments with models, that a car truck which has some freedom of position will always assume or tend to assume a certain characteristic position which has been termed the position of *stable equilibrium*, (Fig. 14), and which might also be termed the position of *least resistance*. (The "gauge" of the track is purposely exaggerated in Figs. 13 and 14). The most characteristic feature of this position of equilibrium or least resistance is that the *rear* axle assumes a *radial* position with respect to the track.

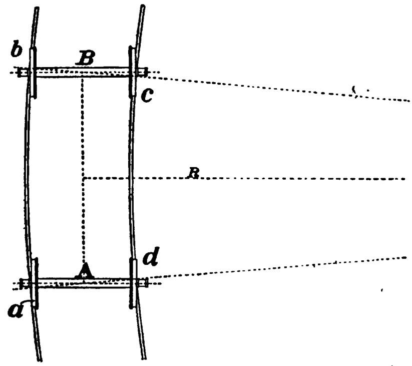

Fig. 13.

Since the two axles of a car-truck are held parallel to each other, owing to the very construction of the truck, the radial position assumed by the rear-axle, A, involves, necessarily, a shifting of the forward axle, B, bodily toward the outer rail, and, at the same time, a change of its angular relation to the track. The result is that the forward wheels no longer run parallel with the

track; the inner wheel tends to run off the inner rail, while the outer wheel tends to run over and across the outer rail, being prevented by the contact of the wheel-flange against the rail-head at b, (Fig. 14), where most of the flange-friction occurs. The relation of the wheel-tread and wheel-flange to the rail is shown more clearly in Fig. 15, which represents the *outer rail* and the *front outer* wheel, when the motion of the wheel and of the car are as indicated by the arrows, and represents the *inner rail* and *forward inner* wheel, when the motions are reversed.

The flange of the *rear outer* wheel, and the flange of the forward inner wheel are both held away from the rail, as seen at *a* and *c* in Fig. 14. The flange of the *rear inner* wheel is usually held close to the inner rail.

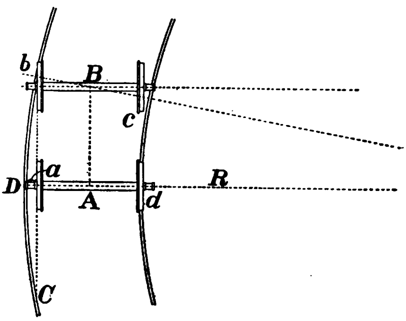

FIG. 14.

Wellington found, experimentally, that a truck would always assume the position indicated in Fig. 14, under all circumstances when allowed to do so; and that, when restrained or disturbed, it would promptly return to this position as soon as the restraining or disturbing force was removed.

He also found that the vertical plane in which the two flanges of the two outer wheels move intersects an arc, (CDb), of the curve of the track, whose chord (Cb) is equal, substantially, to *twice* the wheel-base (y). The distance (a) between the *flange* and the *rail-head*, at the outer wheel, is, therefore, substantially equal to the *versed sine* of an angle whose *sine* is equal to the wheel-base (y), or

$$y = AB = \frac{Cb}{2} = R \sin \beta, \qquad \text{(a)}$$

and $a = R - R \cos \beta = R \text{ vers } \beta. \qquad \text{(b)}$

The distance (a) may be affected somewhat by the axle end-play and by variations in the gauge of the track and in the distance between the flanges of the wheels on the same axle. It was never-

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theless found, by Wellington, to remain substantially constant under all ordinary conditions, so long as the truck can retain the relative position (or the position of "least resistance") indicated in Fig. 14, or for all curves whose radius is *above* a certain critical or limiting value, which value depends upon the wheel-base and also upon the "play" allowed between the wheel-flanges and the rails. (In practice, the "track" gauge is made wider than the "wheel" gauge by an amount representing a "play" ranging between 0.375 inch and 0.75 inch, and averaging 0.5 inch.) When the curve radius is *less* than the critical radius, the curve is too "sharp" for the particular wheel-base, and the rear axle of the truck can then no longer maintain the radial position shown in Fig. 14, but is forced into the position approximating that of "maximum resistance," indicated in Fig. 13. This condition occurs very frequently in street railroad curves, on city streets, where the radius of curvature is, in most cases, necessarily limited, and is, in consequence, below the limiting or critical value at which the truck ceases to assume the position of "least resistance" ("stable equilibrium") in going around the curve. Usually the rails themselves, at the curve, will, by their condition, indicate sufficiently the position assumed by the car trucks in going around the curve. When the wear is about the same at both rails, the indications are that the conditions in going around the curve are substantially as represented in Fig. 13, and that flange-friction occurs at all four wheels, either owing to relatively great length of wheel-base (as on the European steam-roads), or to relatively short radius of curvature (as on street railroads). When the wear is almost wholly confined to the outer rail, the indication is that the conditions allow the trucks to assume the position of "least resistance" in passing around the curve, as is usually the case on most American steam roads. Wellington regarded the wear of rails, at curves, as the "foot prints" of the mechanical forces

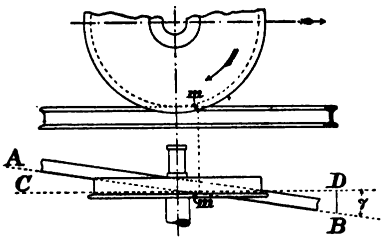

FIG. 15.

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which influence the relative position of the wheels on the track and determine the amount of friction and the consequent amount of additional resistance produced on track curves.

Track curvature is measured and expressed in two different ways:—

(a) In terms of the "*radius*" of the curve.

(b) In terms of a special unit called the "degree" of curvature.

The "radius" notation is that usually employed in Europe, the radius being usually expressed in *meters* on the Continent, and in *chains* (= 66 ft.) in England.

The "degree" notation is the only one employed in the United States and in Canada.

A curve of one degree is one of which an arc having a chord exactly 100 ft. in length, subtends an angle of one (trigonometrical) degree.

If, in the diagram, Fig. 16, we let TS = 100 ft. and $\theta = 1°$, then the arc TQS, subtended by the chord TS, will be a "curve of one degree." (The angle is greatly exaggerated in the diagram). A curve of 2° will be one, (T′ QS′), for which the angle, subtended by a chord (T′ S′) of 100 ft., is $2\,\theta = 2°$. In general, a curve of N° would be one for which the angle, subtended by a chord, T″ S″, of 100 ft., is $N\,\theta = N°$.

When the "central" angle is $\theta = 1°$, the half angle is $\frac{\theta}{2} = 0.5°$, the radius R of which is easily found, by trigonometry. We have

$$R \sin \frac{\theta}{2} = \frac{100}{2} = 50,$$

whence

$$R = \frac{50}{\sin \theta/2} = \frac{50}{\sin (0.5)°} = 5729.7 \text{ ft.}$$

For an angle of 2°, the radius is substantially one-half as great. In practical work, it is assumed that the radius, R, is inversely proportional to the angle (D), and the following formulæ are generally used:—

$$R = \frac{5730}{R}; \text{ whence } D = \frac{5730}{R}.$$

The error is practically negligible for small angles (under 10°). For larger angles, when greater accuracy is desired, the chord is

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taken equal to 50 ft. instead of 100 ft. in measuring or in laying out the curve.

The resistance due to track curvature is, as already stated, due mostly to sliding friction. This friction takes the form of "wheel-flange friction," when it occurs between the wheel-flanges and the side of the rail-head, and of "wheel-tread friction" when it occurs between the wheel-treads and the rail surface.

The wheel-flange friction, which is the principal element of curve resistance, may occur, as already seen, either at all four wheels (Fig. 13), or chiefly at one or two wheels, (Fig. 14), of the truck.

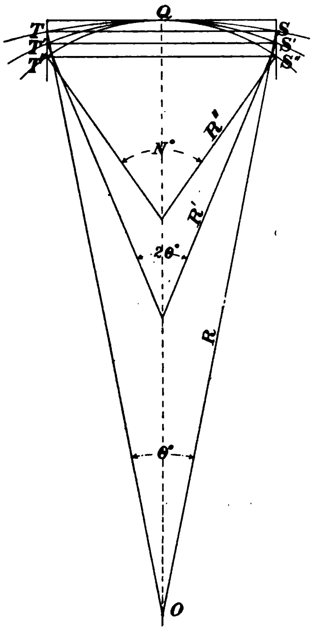

Fig. 16.

The wheel-tread friction results from slipping of the wheel on the rail, both *longitudinally* and *laterally*. The longitudinal slip is due partly to the difference in length of the inner and outer rails, and partly to the difference in "effective" periphery of the wheels (due to "coned" treads), the position of the wheels being seldom, if ever, such that the difference in lengths of rail is exactly compensated by the difference in effective wheel periphery, for the two sides of the track. The lateral slip of the wheel-tread is due principally to the obliquity of position of the wheels (Fig. 15). It can be easily shown and seen that the motion of the wheel on the track can be resolved into two components, one of which (mD) is parallel to the plane of the wheel, the other, (DB), being perpendicular thereto. The latter, which is proportional to the sine of the angle of wheel inclination, γ, represents the "lateral" slip. This slip occurs at all four wheels of the truck, under the conditions represented in Fig. 13, and at the wheels of the front axle (B) only, under the conditions represented in Fig. 14.

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(The "mechanics" of curve resistance are discussed at considerable length in Wellington's "Railway Location," Chapter VIII).

Many practical tests of curve resistance have been made, at different times and in different countries. The results of European tests are not usually applicable to American practice without correction, because rigid trucks with relatively long wheel-bases are the general rule in Europe, while pivoted trucks with relatively short wheel-bases are the general rule in America.

When the radius of track curvature is above 3000 ft., the curve resistance is very small and is practically negligible. As the radius decreases, the curve resistance increases.

Wellington estimated the curve resistance for freight cars at ordinary speeds to range between ½ lb. and ⅔ lb. per ton per degree of curvature, the first being the resistance for a track which is in first class order, and the second, the resistance for a somewhat rough track with worn rails. These values are considered somewhat low. The Master Mechanics Association recommended, in 1897, an allowance of 0.7 lb. per ton per degree of curvature for cars, and twice this amount for locomotives.

On electric roads, the allowance for curve resistance should undoubtedly be larger than on steam roads. As we have already seen, the prevailing conditions, in the greater number of curves, are incompatible with those of minimum resistance (Fig. 14), being, on the contrary, favorable to maximum resistance, (Fig. 13). The condition of the track, at curves, which may be as good as on steam roads in the case of suburban electric roads built upon a private right of way, is always inferior in the case of roads built upon public streets and roads. For this reason the allowance for curve resistance on electric roads varies from 0.75 to 0.85 lb. or more per ton per degree of curvature for *trailer* cars, and from 0.8 to 1.0 lb. or more, per ton per degree for *motor* cars. In the case of electric *trains* consisting of motor cars and trailer cars, on suburban roads, and on rapid transit roads, the allowance made for curve resistance ranges from 0.8 to 0.95 lbs. per ton per degree of curvature.

The amount of curve resistance in any given case is greatly influenced by the very same conditions which influence the co-

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efficient of adhesion (rail-friction). The well known fact, already noted, that curve resistance is decreased by lubrication ("greasing") of the track at curves is obviously a consequence of the reduction of the coefficient of friction between the rail-head and the wheel-flange and wheel-tread. It is found that, as in the case of "adhesion," the sliding-friction at curves may also be reduced by the "lubricating" effects of water (rain), snow, ice, sleet, mud, etc. It was found, in one instance, in some tests of curve resistance made in France, that even a fog produced a lubricating effect sufficiently great to cause a perceptible decrease in the curve resistance.

It is known that the direction and force of the wind are of importance as factors influencing flange-friction, both on a straight track and on curves. In one case, in the test just mentioned, the resistance of the same train running over the same portion of road and in the same direction after an interval of one hour, was doubled, in consequence of a difference in the weather and wind conditions.

Since sliding friction is known to decrease as the rubbing velocity increases, (see Fig. 9, April, 1904), it might be expected that curve resistance will decrease with the train velocity. The results of all tests of curve resistance made in this country indicate a slight decrease as the velocity increases. The exact relation between the curve resistance and the velocity has not yet been determined or formulated.

It is the general practice, on all roads, to limit the speed of trains in going around curves. This is not done to save power, as the preceding considerations show sufficiently. It is done to avoid accidents, such as might result from derailment or from the action of centrifugal force. The sharper the curve, the lower the limiting speed. The relation between the allowable speed (V) and the degree of track-curvature (D) is usually expressed thus

$$V = \frac{K}{\sqrt{D}}$$

where K = a constant whose value may range between 60 and 180 according to the "margin of safety" desired.

Compensating Grades. When curves occur on severe grades, it is customary, on steam roads, to reduce the percentage of grade,

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at the place where the curve occurs, the object being to "compensate" for the extra train resistance due to the curve by an equivalent reduction in the train resistance due to the grade. The amount (C), by which the grade percentage (G %) is to be reduced at a curve may be expressed thus:—

$$C = \frac{Df}{20}.$$

Example, suppose a curve of 8.5° to occur on a 1.75 % grade, the curve resistance (*f*) being assumed 0.7 lb. per ton per degree. We will have

$$C = \frac{8.5 \times 0.7}{20} = \frac{5.95}{20} = 0.296\,\%.$$

which is the percentage of the "compensating grade." The actual percentage of the grade at the curve will be:—

$$G - C = 1.75 - .296 = 1.454\,\%.$$

The percentage (G) on the rest of the grade will have to be increased to make up for the "loss of rise" due to the compensating grade. The amount of this increase will be small when the curve is short as compared with the whole grade; and it will increase as the proportion of the length of curve to the total length of grade increases.

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THE DISTRIBUTION OF PRESSURE AND CURRENT OVER ALTERNATING CURRENT-CIRCUITS.

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(*Continued from p. 225, Vol. IV, No. 4.*)

Determination of the constants of a circuit from its final sending-end impedances.

If at the sending end A of a circuit (Fig. 2) we measure the impedance Z_f of the loop when free at the distant end, and also the impedance Z_g of the loop when shorted at the distant end, the constants of the circuit are determinable from the two measurements, if the circuit is uniform. The measurements are supposed to be made with voltmeter, ammeter, and wattmeter; so that both the magnitude and the angle of the impedances are found.

If we reduce the impedance of the loop to the impedance per wire, we have, for the sending-end impedance with distant end free:—

$$z_f = \frac{Z_f}{2} \quad \text{ohms per wire} \quad . \quad . \quad . \quad . \quad (61)$$

and for the sending-end impedance with the distant end to ground, or shorted:—

$$z_g = \frac{Z_g}{2} \quad \text{ohms per wire} \quad . \quad . \quad . \quad . \quad (62)$$

Then from formulas (41) and (51) we have

$$\frac{z_g}{z_0} = \frac{z_0}{z_f} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (63)$$

or the initial sending-end impedance is always a third proportional to the final sending-end impedances free and grounded; or,

$$z_0 = \sqrt{z_f . z_g} \quad \text{ohms} \quad . \quad . \quad . \quad . \quad . \quad (64)$$

that is, the initial sending-end impedance is the vector geometric mean of the final free and ground sending-end impedances when the wire is uniform.

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Thus, taking a cable pair of paper-covered No. 19 A. W. G. copper wires, (0.912 mm. in diameter), as defined in Tables II and IV, with Figs. 5 and 6, suppose that at the frequency of nearly 40 cycles per second (39.8 = 250 radians per second), a loop 30 miles (48.28 kilometres) long, offers an impedance $Z_g = 2{,}286 \underline{|26°.35'}$ ohms, when shorted at the distant end, and an impedance $Z_f = 1970.4 \underline{|63°.15'}$ ohms, when freed at the distant end. From these we have the ground and free sending-end impedances per wire $z_g = 1{,}143 \underline{|26°.35'}$ and $z_f = 985.2 \underline{|63°.15'}$ ohms, respectively. Consequently $z_0 = \sqrt{1{,}143 \underline{|26°.35'} \times 985.2 \underline{|63°.15'}} = \sqrt{1{,}126{,}000 \underline{|89°.50'}} = 1{,}061 \underline{|44°.55'}$, ohms, which agrees with the entry in Table IV.

Again, by (41) and (51) we have:—

$$\tanh La = \sqrt{\frac{z_g}{z_f}} \qquad \qquad (65)$$

$$\text{or} \qquad a = \frac{1}{L} \tanh^{-1} \sqrt{\frac{z_g}{z_f}} \qquad \text{per mile or kilometre} \quad (66)$$

Taking the last case considered, we have

$$\tanh La = \sqrt{\frac{1{,}143 \underline{|26°.35'}}{985.2 \underline{|63°.15'}}} = \sqrt{1.160 \underline{|36°.40'}} =$$

$1.077 \underline{|18°.20'}$ From which by the aid either of Table VIII, Fig. 10, or formula (100) in the Appendix, $La = 1.2728 \underline{|45°.06'}$

So that $a = \dfrac{1.2728 \underline{|45°.06'}}{48.28} = 0.026{,}36 \underline{|45.°06'}$ per wire kilometre, which agrees with the entry in Table II.

From the values of z_0 and a thus determined, the conductor-impedance and dielectric-admittance per wire kilometre may be computed by formulas (18) and (19).

From these again, and the frequency, we may find r, l, g and c by (10) and (16).

It may be observed that in the case of a well insulated direct-current circuit, the sending-end resistance with distant-end free, is of course always greater than the sending-end resistance with the distant-end shorted. Even with poor insulation, the sending-end resistance free always tends to exceed the sending-end resistance grounded, the two values only becoming equal when the line is exceedingly long, or the leakance exceedingly great. But in the

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case of alternating-current circuits this condition does not hold. That is to say the sending-end impedance of a circuit, or of a line, with the distant end free, will always be less than with the distant end grounded (or shorted), when the attenuation-length exceeds a certain value, unless the insulation be very low. An inspection of Tables VIII and IX, or of Figs. 10 and 11, will show that z_f the sending-end impedance free falls below z_g the sending-end impedance grounded, after the attenuation-length reaches:—

1.2	for	the	imaginary-real	ratio		1
0.87	"	"	"	"	"	2
0.82	"	"	"	"	"	3
0.81	"	"	"	"	"	4
0.78	"	"	"	"	"	10

So that stating the facts roughly, we may say that a line will offer less impedance when freed at the distant-end than when shorted or grounded at the distant-end after its attenuation-length $L\alpha$ reaches about unity. Although no series of measurements seems yet to have been reported on this question, yet it has already been observed that the impedance of a telegraph circuit freed at the distant-end was less than that of the same circuit shorted.

The circuit connected through an impedance Z_r at the distant-end.

If the distant-end of the circuit in Fig. 1 be closed through an impedance Z_r ohms, each wire may be regarded as grounded through an impedance of $\frac{Z_r}{2} = z_r$ ohms, as in Fig. 3. A current strength of i amperes delivered through this impedance to ground will determine a pressure $e = i\, z_r$ volts at C, Fig. 7. Consequently, from the right-hand side of (26)

$$i = \frac{e}{z_0 \sinh L\alpha + z_r \cosh L\alpha} \quad \text{amperes} \quad . \quad . \quad (67)$$

$$= \frac{e}{\sqrt{z_0^2 - z_r^2}\, \sinh (L\alpha + \gamma)} \quad \text{amperes} \quad . \quad . \quad (68)$$

$$\text{Where } \gamma = \tanh^{-1} \left(\frac{z_r}{z_0}\right)$$

Comparing this result with formulas (45) and (46), it is evident that the effect of adding the impedance z_r to the distant-end of

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the line is to increase the attenuation-length $L\alpha$ in the expression for receiving-end impedance by a quantity $\tanh^{-1}\frac{z_r}{z_0}$ and also virtually to reduce the initial sending-end impedance from z_0 to $\sqrt{z_0^2 - z_r^2}$ ohms.

Moreover, comparing (67) and (46) it is clear that the insertion of the impedance z_r into the circuit at the receiving-end has increased the receiving-end impedance in the ratio

$$\frac{Z_1}{z_1} = 1 + \beta \coth L\alpha \qquad . \quad . \quad . \quad . \quad . \quad . \quad (69)$$

As an example we may consider a New York–Chicago unloaded aerial telephone line reported to have a length of 900 miles (1,448.4 kilometres), a resistance of 1.305 ohms per wire kilometre, a capacity of 1.056×10^{-8} farad per wire kilometre, an inductance of 1.118×10^{-3} henry per wire kilometre, and negligible leakance. These data give at the angular velocity $\omega = 5000$ radians per second:—

$\alpha = 0.017{,}41 \ \underline{|83^\circ.26'} = 0.001{,}991 + j\ 0.017{,}29$ per kilometre.

$z_0 = 329.7 \ \overline{|6^\circ.34'}$ ohms per wire

$L\alpha = 25.218 \ \underline{|83^\circ.26'} = 2.884 + j\ 25.04$

The receiving-end impedance of this 900-mile line when grounded, or shorted, at the distant-end, assuming no terminal underground cable, is at the same frequency:—

$$z_1 = 329.7 \ \overline{|6^\circ.34'} \ \sinh 25.218 \ \underline{|83^\circ.26'} \qquad \text{by (46)}$$
$$= 2{,}938 \ \overline{|11^\circ.52'} \qquad \text{ohms per wire.}$$

If now, a receiving telephone having an equivalent resistance of 100 ohms, and an inductance of 0.1 henry be inserted in the circuit at the distant-end, the impedance of the instrument at this frequency will be $Z_r = 100 + j\ 500 = 509.9 \ \underline{|78^\circ.41'}$ ohms. Half of this may be regarded as being inserted in each wire to ground at the distant-end, or $255 \ \underline{|78^\circ.41'}$ ohms per wire. Substituting in formula (69) the value $\beta = \dfrac{255 \ \underline{|78^\circ.41'}}{329.7 \ \overline{|6^\circ.34'}} = 0.7733 \ \underline{|85^\circ.15'}$ and finding with the aid of formula (99) in the appendix, $\coth L\alpha = 1{,}0065 \ \underline{|8^\circ.1'}$, we have

$$\frac{Z_1}{z_1} = 1 + 0.7733 \ \underline{|85^\circ.15'} \times 1.0065 \ \underline{|0^\circ.4'}$$
$$= 1 + 0.7784 \ \underline{|85^\circ.19'} = 1.316 \ \underline{|36^\circ.06'}$$

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The receiving telephone therefore increases the receiving end impedance by 31.6%, or to 3,866 $\underline{|24°.14'}$ ohms per wire.

In the case of long circuits, near the limits of transmission range, coth $La = 1$ very nearly, and we have from (67)

$$i = \frac{e}{(z_0 + z_r)\ \sinh La} \text{ amperes} \quad . \quad . \quad . \quad . \quad (70)$$

or the receiving-end impedance becomes

$$Z_1 = (z_0 + z_r) \sinh La \qquad \text{ohms} \quad . \quad . \quad . \quad . \quad (71)$$

$$\text{and } \frac{Z_1}{z_1} = \frac{z_0 + z_r}{z_0} = 1 + \beta \quad . \quad . \quad . \quad . \quad . \quad . \quad (72)$$

If the circuit is an unloaded cable; so that z_0 has a well defined negative reactance; while z_r has a similarly well defined positive reactance, or reactance due to self-induction, $z_0 + z_r$ may be numerically less than z_0; or β may be negative. That is, the receiving-end impedance may be reduced, or the received current increased, by the insertion of the receiving instrument; a condition that would be impossible in an ordinary direct-current circuit.

If we substitute $e = i\ z_r$ in (28) and (29), we obtain for the sending-end impedance per wire when the impedance z_r is inserted to ground at the receiving-end:—

$$z_A = z_0 \left\{ \frac{\tanh La + \beta}{1 + \beta \tanh La} \right\} = z_0 \tanh (La + \gamma) \text{ ohms} \quad . \quad . \quad (73)$$

$$\text{where } \tanh \gamma = \beta = \left(\frac{z_r}{z_0}\right)$$

Comparing this result with formula (51) we find that the effect of adding the impedance z_r to the distant-end of the line, is virtually to increase the attenuation-length La in the final sending-end impedance by the complex quantity γ whose hyp. tangent is $\left(\frac{z_r}{z_0}\right)$.

When La is large, its hyp. tangent approaches unity, and is scarcely altered by the addition of γ. In other words, the sending-end impedance of an electrically long line is not sensibly altered by inserting an impedance at the distant-end.

The ratio of the current received through the impedance z_r, to the current sent at the sending-end is by (68) and (73)

$$\frac{i}{I} = \cosh \gamma \ \text{sech}\ (La + \gamma) \quad . \quad . \quad . \quad . \quad . \quad . \quad (74)$$

It appears from formulas (67) to (72) that in electric telephony

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the limiting distance to which speech can be commercially carried depends, with a given type of transmitter and receiver, upon the receiving-end-impedance of the circuit including the receiver. Observations have shown* that paper-insulated cable telephone circuits behave in regard to attenuation of speech, as though the transmission were effected at or near the frequency of 800 cycles per second ($\omega = 5{,}000$ radians per second), instead of through a wide range of vocal frequencies, such as are known to exist in the speaking tones. This single frequency may, therefore, be called the mean, or virtual telephonic frequency.

In the inaugural address by Mr. John Gavey before the Institution of Electrical Engineers (London) *Journal*: Nov. 9, 1905, p. 28, there is a list of the commercial limiting ranges of speaking as observed experimentally on several different types of circuit. The data thus provided appear in Table XII on the next two pages.

The first two columns give the experimentally determined limiting length of the circuit (in miles and kilometres) for commercial telephonic transmission, or what may be called the long-distance commercial limit. The next three columns give the resistance, the inductance and the capacity of the circuit per loop-mile. The three following columns give the corresponding quantities per wire-kilometre. The next or ninth column gives the weight of the copper conductor in each wire of the circuit. The next two columns give the initial sending-end impedance per wire and the attenuation constant, in kilometre units. The twelfth column gives the vector attenuation-length, the real and imaginary components of which follow. The fifteenth column gives the hyp. sine of the vector attenuation-length which is practically the same as the hyp. sine of the real attenuation-length. Next follows the receiving-end impedance per wire of the circuit when grounded at the distant-end. The next column gives the impedance ($z_0 + z_r$) vector sum of the sending-end and receiver impedances, on the assumption that the receiver used had an effective resistance of 100 ohms and an effective inductance of 100 millihenrys; which

* See paper on "Loaded Telephone Lines in Practice" by Dr. Hammond V. Hayes. Trans. International Electrical Congress, St. Louis, Vol. III, pp. 643 and 649.

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Table XII.

Attenuation-Constants, Attenuation-Lengths and Receiving-End Impedances of eleven circuits of commercial-limit telephonic range from experimental observations reported in Mr. Gavey's inaugural address to the Institution of Electrical Engineers.

Length of each wire in loop circuit.		Res. per loop mile.	Ind. per loop mile.	Capacity per loop mile.	Res. per wire kilometre	Ind. per wire kilometre	Capacity per wire kilometre	Weight of each conductor	Initial sending-end Impedance per wire.	
Miles.	Kilometres.	Ohms.	Henrys $\times 10^{-3}$	Farads $\times 10^{-8}$	r ohms.	l henrys $\times 10^{-4}$	c farads $\times 10^{-8}$	Kilogrammes per kilometre	z_0 ohms	
26	41.84	175.64	1.000	7.0	54.57	3.107	8.7	2.818	354.3	$\lfloor 44^{\circ}.11'$
43	69.2	86	1.000	5.5	26.71	3.107	6.833	5.636	280	$\lfloor 43^{\circ}.20'$
63	101.4	42	1.000	5.6	13.05	3.107	6.958	11.27	194.3	$\lfloor 41^{\circ}.37'$
127	204.4	11.7	1.000	6.5	3.635	3.107	8.076	42.27	98.9	$\lfloor 33^{\circ}.26'$
88	141.6	12.9	1.65	12.0	4.007	5.126	14.91	39.18	79.9	$\lfloor 28^{\circ}.59'$
39	62.77	43	1.00	12.8	13.36	3.107	15.91	11.27	130	$\lfloor 41^{\circ}.41'$
473	761.2	11.90	3.76	0.839	3.697	11.68	1.043	42.27	364.2	$\lfloor 16^{\circ}.10'$
626	1007.5	9.0	3.66	0.862	2.796	11.37	1.071	56.36	343.9	$\lfloor 13^{\circ}.06'$
903	1453	6.0	3.545	0.893	1.875	11.02	1.11	84.54	323.8	$\lfloor 9^{\circ}.24'$
1075	1730	4.5	3.44	0.919	1.413	10.69	1.142	112.7	311.2	$\lfloor 7^{\circ}.25'$
1582	2546	2.97	3.31	0.958	0.945	10.25	1.19	169.1	298.4	$\lfloor 5^{\circ}.14'$

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Attenuation constant at angular velocity 5000 radians per second.		Attenuation Length.		Real component of Attenuation Length.	Imaginary component of Attenuation Length.	Hyp. sine of Attenuation Length.	Receiving-end Impedance per wire grounded.	$z_0 + z_r$	Receiving end Impedance per wire with Z_r	Nature of Insulation
a per kilometre		La		La_1	La_2	sinh La	z_0 sinh La ohms	ohms.	(z_0+z_r) sinh La ohms.	
0.1541	45°.49′	6.448	45°.49′	4.494	4.632	44.74	15,850	304	13,600	Paper cable.
0.0956	46°.40′	6.616	46°.40′	4.541	4.814	46.89	13,120	260	12,200	" "
0.0671	48°.24′	6.855	48°.24′	4.551	5.126	47.357	9,202	229.7	10,880	" "
0.03995	56°.34′	8.166	56°.34′	4.499	6.815	44.60	4,413	236.2	10,540	" "
				4.521					11,805	Means.
0.05955	61°.02′	8.434	61°.02′	4.085	7.380	29.713	2,374	242.9	7,218	G. P. cable.
0.10345	48°.19′	6.493	48°.19′	4.318	4.849	37.522	4,878	219.9	8,252	G. P. quad.
				4.202					7,735	Means.
0 01857	73°.50′	14.135	73°.50′	3.937	13.58	25.623	9,332	426.5	10,930	Aerial wire.
0.01842	76°.55′	18.56	76°.55′	4.201	18.07	33.369	11,475	421.1	14,050	" "
0.01797	80°.37′	26.12	80°.37′	4.258	25.77	35.327	11,440	418.7	14,790	" "
0.01777	82°.36′	30.75	82°.36′	3.960	30.49	26.219	8,158	415.9	10,910	" "
0.01776	84°.47′	45.23	84°.47′	4.110	45.05	30.465	9,090	412.5	12,570	" "
				4.093					12,650	Means.

would give a loop impedance of $100 + j\,500$ ohms at a frequency corresponding to 5,000 radians per second. The last column but one gives the receiving-end impedance of the circuit with such average type of receiver.

It will be observed that the four paper-insulated types of cable have a mean limiting real attenuation-length of 4.52.. Their mean receiving-end impedance is 11,800 ohms per wire (23,600 ohms to the circuit). The five aerial wires give a mean limiting real attenuation-length of 4.093, and their mean receiving-end impedance is 12,650 ohms per wire (25,300 ohms per circuit). If the receiver actually used in the tests had a different reactance from that assumed, the receiving-end impedances would be modified, but their ratio would not be much altered.

The mean limiting real attenuation-length of the gutta-percha cables is 4.2 and their mean receiving-end impedance 7,735 ohms per wire (15,470 per circuit). It is not clear why the gutta-percha cable receiving-end impedance should average so much less than the paper cable receiving-end impedance. It is possible, judging from the known behavior of rubber-insulated electric-light cables, to account for the discrepancy by the existence of dielectric hysteresis, or waste of energy, in the gutta-percha under alternating stress. This would mean that the leakance g, instead of being zero, corresponding to perfect insulation, would virtually attain appreciable magnitudes. Such a condition has been discovered in paper telephone cables imperfectly dried, so as to offer high insulation, but distinct hysteretic loss. If, for example, $g = 8 \times 10^{-6}$ in the case of the 88-mile gutta-percha cable, the real attenuation-length would be increased to 4.5 and the receiving-end impedance to 11,000 ohms per wire. This question as to the existence of a hysteretic g might readily be settled experimentally.

The results indicate, however, that the long-distance limit of telephone circuits is such as makes their receiving-end impedance about 25,000 ohms with the existing types of telephone apparatus at the mean telephonic frequency of $\omega = 5{,}000$. Corresponding to this impedance the overhead wires attain a real attenuation-length La_1 of about 4.1 and the paper cables about 4.5.

It is reported, however, in the same address, that conversations

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have been held by experts over 60 miles (96.56 kilometres) of the paper cable referred to on the first line of Table VII. On such a circuit, the real attenuation-length would be increased from 4.494 to 6.555 and the receiving-end impedance through the 100 millihenry telephone to 90,000 ohms per wire (180,000 ohms per circuit).

An easy commercial limit of telephonic transmission has been offered by Dr. Campbell at $La_1 = 3.2$.*

The largest sizes of aerial copper wire in Table XII begin to develop extra resistance due to skin-effect at the frequency of $\omega = 5{,}000$ radians per second ($n = 796$ cycles per second). In order to employ rational values, the quantities appearing in the sixth column have been slightly corrected for skin effect by the first-approximation formula

$$r' = r\left(1 + \frac{0.0208}{r^2}\right) \text{ ohms per kilometre} \quad . \quad . \quad (75)$$

where r is the resistance per wire in ohms per kilometre to steady currents and r' the value corrected for the skin effect to first approximation. Thus a cylindrical copper wire having a resistance of 1 ohm per kilometre, offers a virtual resistance of 1.0208 ohms per kilometre to alternating currents at 800 cycles per second, or about 2% extra.

Loaded Telephone Circuits.

The effect of distributed inductance in a telephone line is to increase the angle of the vector conductor-impedance $r + j\,l\omega$ and, therefore, to increase the angle of the vector attenuation-constant a, so as to diminish the real component a_1 on which attenuation depends, while increasing the imaginary component a_2 on which the wave-length depends. It has been found that the insertion of inductance in lumps or coils may have a similar influence in reducing attenuation and increasing the range of transmission, provided that the electrical distance between successive coils is not too great.

* G. A. Campbell. *Phil. Mag.* March, 1903.

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Formulas (67) to (73) show that the effect of inserting an impedance into a circuit at the receiving-end, is virtually to increase the attenuation-length $L\alpha$ of the circuit; so that if the length be regarded as fixed, the attenuation-constant α is increased. This proposition also applies when inductance coils are inserted at suitable regular intervals along the line. The attenuation-constant α is thereby increased; but analyzed into components, the increase occurs in the imaginary part α_2, the real part α_1 being diminished.

If we denote the new attenuation-constant of the loaded line

by $\qquad \alpha' = \alpha'_1 + j\,\alpha'_2 \qquad$ . . . . (76)

it can be proved that

$$\cosh L'\alpha' = \cosh L'\alpha + \beta \sinh L'\alpha \qquad (77)$$

where

$$\beta = \frac{z'}{2z_0} \qquad (78)$$

z' being the impedance of any single loading coil per wire; that is

$$z' = r' + j\,l'\omega \quad \text{ohms} \qquad (79)$$

r' being the equivalent resistance (ohmic resistance plus the increase due to hysteretic and eddy-current losses) and l' the inductance of one load coil per wire of the circuit. L' is the distance between successive load coils in miles or kilometres, or the length of the line sections, separating the loads. The formula (77) may be written in the form

$$\alpha' = \frac{1}{L'}\cosh^{-1}(\cosh L'\alpha + \beta \sinh L'\alpha) \quad \text{per mile or kilometre} \qquad (80)$$

which expresses the attenuation-constant of the loaded line in terms of the original or unloaded attenuation-constant, the load impedances, the original sending-end impedance, and the load-sections L'.

Thus, taking a paper cable of $r = 27.96$ ohms, $c = 0.074{,}55$ microfarad and $l = 0.56$ millihenry, all per wire kilometre, and inserting at intervals of 1.2 kilometres a choking coil of 15 ohms equivalent resistance and 0.225 henry, in each wire of the circuit, required the attenuation-constant of the loaded line at the angular velocity of 5,000 radians per second. The unloaded attenuation-constant is obtained by formula (10) in the usual way and is found to be:—

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$$a = 0.102,1 \,|\!\underline{45^\circ.54'} = 0.071,1 + j\,0.073,4 \text{ per kilometre,}$$

while the initial sending-end impedance unloaded, by (16), is 274 $|\!\underline{44^\circ.06'}$ ohms at this angular velocity. The unloaded attenuation-length of a 1.2-kilometre section is

$$L'\,a = 0.122,52 \,|\!\underline{45^\circ.54'} = 0.085,32 + j\,0.088,08.$$

We find, with the aid of formulas (95) and (97) in the Appendix, the hyp. cosine and sine of this attenuation-length, multiplying the latter by $\beta = 2.053 \,|\!\underline{133^\circ.20'.25''}$; so that by (80) we obtain

$$a' = 0.605,2 \,|\!\underline{88^\circ.51'} = 0.012,1 + j\,0.605,1 \text{ per kilometre}$$

as the attenuation-coefficient of the loaded line. The loading has increased the attenuation-coefficient about six times; but has reduced the real component six times, the angle having increased from 45°.54′ to 88°.51′. The wave-length of the loaded line, by (4) will be $\lambda' = \frac{6.283}{0.6051} = 10.37$ kilometres, so that there will be 8.64 coils per actual wave-length at this frequency.

The velocity of the waves, by (9) will be $v' = \frac{5000}{0.6051} = 8,263$ kilometres per second, or about eight times less than in the unloaded cable. With coils at 1.2 kilometres apart, there would be 6,886 coils passed by an advancing wave per second, as given by the strict formula

$$n' = \frac{\omega}{L'\,a_2'} \quad \ldots \quad \text{coils traversed per second} \qquad (81)$$

Instead of taking the fundamental formula (80) for the loaded-line attenuation-cœfficient, we might consider the line as possessing an evenly distributed extra resistance and inductance equal to that contained in all the load coils together. That is, we might consider the line as having a conductor resistance of $(r + r'')$ ohms per kilometre and an inductance of $(l + l'')$ henrys per kilometre; where r'' and l'' are respectively the extra equivalent resistance and inductance per kilometre due to the load coils smoothed out, or evenly distributed, along the circuit. In the case considered, $r + r'' = 27.96 + 12.5 = 40.46$ ohms per kilometre and $(l + l'')\,\omega = 0.88 + 937.5 = 938.4$ ohms per kilometre. By formula (10) the attenuation-coefficient of the smoothly loaded

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line would be $a'' = 0.591{,}7 \underline{|88^\circ.46'} = 0.012 + j\,0.591{,}6$ per kilometre, a result not differing greatly from that obtained by (80) for the lumpy line. In any smooth line possessing considerable inductance as well as capacity, the imaginary component a_2 of the attenuation coefficient is always approximately $\omega\sqrt{c\,l}$ per kilometre; so that the velocity of the waves, by (9), is

$$v = \frac{\omega}{\omega\sqrt{c\,l}} = \frac{1}{\sqrt{c\,l}} \quad \text{kilometres per second} \quad . \quad (82)$$

In a smoothly loaded line, therefore, or a loaded line regarded as smooth, $v'' = \dfrac{1}{\sqrt{c\,(l + l'')}}$ kilometres per second . (83)

approximately, and this velocity is substantially the same on the same line for a wide range of frequencies. The number of coils traversed by any such wave per second will therefore be

$$n'' = \frac{v''}{L'} = \frac{1}{L'\sqrt{c\,(l + l'')}} \quad \text{coils per second} \quad . \quad . \quad (84)$$

practically constant for all waves. In the case considered, the velocity of transmission over the loaded line, assumed smooth, is $v'' = 8{,}453$ kilometres per second, and

$$n'' = \frac{1}{1.2\sqrt{7.455 \times 10^{-8}\,(0.187{,}68)}} = 7{,}044 \text{ coils per second.}$$

Formula (80) although reliable, is tedious to work with arithmetically. It has, however, been carefully investigated.* The results show that when the line is originally almost devoid of inductance, as in a telephone cable, and is loaded with a total equivalent resistance equal to half its conductor-resistance ($r'' = r/2$), the assumed smooth-line attenuation-constant a'' is practically identical with the value a' computed from the rigid formula (80), as far as 9 coils per smooth wave-length λ'', as found by the formula

$$\lambda'' = \frac{1}{n\sqrt{c\,(l + l'')}} \quad \text{miles or kilometres} \quad . \quad . \quad (85)$$

that is as far as $L' = \dfrac{\lambda''}{9}$ " " " . . (86)

For wider spacing, greater lumpiness, or higher frequency, the following results are given:—

* G. A. Campbell, loc. cit.

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For 8 coils per wave, or $L' = \frac{\lambda''}{8}$, α'_1 is 1 % greater than α''_1.
" 7 " " " " " " $\frac{\lambda''}{7}$, " " 2 " " " "
" 6 " " " " " " $\frac{\gamma''}{6}$, " " 3 " " " "
" 5 " " " " " " $\frac{\lambda''}{5}$, " " 7 " " " "
" 4 " " " " " " $\frac{\lambda''}{4}$, " " 16 " " " "
" 3 " " " " " " $\frac{\lambda''}{3}$, " " over 200 % " " "

These results will differ to some extent with the ratios $\frac{r''}{r}$ and $\frac{l''}{l}$. They represent, however, that the smooth real attenuation constant α''_1 becomes unreliable if there are fewer than 4 coils per smooth wave-length λ'', and that the line practically absorbs all frequencies above that which allows π coils per smooth wave-length. A loaded cable is, therefore, a wave-sieve. All frequencies above the critical frequency

$$n = \frac{1}{\pi \; L' \; \sqrt{c\,(l + l'')}} \quad \text{cycles per second} \; . \quad . \quad . \quad (87)$$

$$\text{or } \omega = \frac{2}{L' \; \sqrt{c\,(l + l'')}} \quad \text{radians per second} \; . \quad . \quad (88)$$

will be stopped and absorbed by the cable; while frequencies below this critical value will be aided or assisted by the loading. In the case considered $n = 2{,}242$ cycles-per-second and $\omega =$ 14,088 radians-per-second.

Since it has been found in practice that $n'' = 7{,}000$ coils per second is a satisfactory rate of load traversing,* and since $\frac{n''}{\pi}$ is the highest frequency that can pass over the cable, it follows that practical telephony does not require the transmission of any frequency above 2,228, and if the relatively high extra attenuation in the vicinity of π coils per smooth wave-length be taken into account, it seems likely that 2,000 cycles per second is the highest frequency necessary to be maintained in telephonic transmission.

* H. V. Hayes, loc cit.

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If we have π coils per smooth wave at 2,228 cycles-per-second, we shall have $2\ \pi$ coils per wave at 1,114 cycles-per-second, $3\ \pi$ coils per wave at 743 cycles-per-second and so on for lower frequencies. If there are 7,000 coils struck per second by advancing waves, there will be 8.8 coils per smooth wave at the mean telephonic frequency of 796 cycles per second corresponding to $\omega = 5{,}000$.

The reduction of the real-attenuation-constant is not the only effect of loading a line. The initial sending-end impedance z_0 becomes also modified, and is markedly increased. As shown in formula (17), the value of this quantity tends to that of $\sqrt{\frac{l}{c}}$ ohms, and quadrupling l, for instance, tends to double z_0. Thus in the case above considered the initial sending-end impedance of the unloaded line was $z_0 = 274\ |\overline{44°.06'}$ ohms. After the loading (considered as smooth), the value becomes by formula (16) $z''_0 = 1{,}587.5\ |\overline{1°.14'}$ ohms; while using the simpler formula (17) we get $z''_0 = 1587\ |\overline{0°}$ ohms. This represents a nearly six-fold increase in the initial sending-end impedance due to loading. The effect of this in the expression for the receiving-end impedance (67) $z_0 \sinh \mathrm{L}a + z_r \cosh \mathrm{L}a_1$ is to increase that impedance very appreciably. On a very short line, grounded at the distant end, formula (49) shows that the receiving-end impedance becomes $z_0\, \mathrm{L}a$. A short loaded line would under such conditions compare very unfavorably with the same line unloaded, both because of the increase in z_0, and because of the increase in $\mathrm{L}a$. In other words, the received current to ground would be much less over the loaded line than over the unloaded line. The introduction of the receiving instrument z_r somewhat improves the relative behavior of the loaded line; but at best the strength of current received over the short loaded line will be less than over the short unloaded line with such values of the impedance z_r as are used in practice. This means that it is practically worse than useless to load an electrically short line, the effect of the greater z_0 more than compensating for the reduction in a'_1. It is only when a short line may have to be connected to a long one, that loading it seems to offer any advantage. Even on a very long line, where the loading may make telephonic transmission practicable that would otherwise be impossible, the receiving-end impedance is

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increased by reason of the rise in z_0, and the full benefit of the reduced real attenuation-constant cannot be secured. It is, however, theoretically possible to regain it by rewinding the sending and receiving apparatus. A "terminal taper" or gradual reduction of the loading near and towards the ends of the circuit may produce a similar beneficial effect, ordinarily attributed to diminution of reflection losses. This method of regarding the matter is undoubtedly correct, but attaches to the unsteady state, or to the few cycles in which building up of current occurs. The effect, in the steady state, of reflections in the preceding unsteady state is faithfully presented by the values of z''_0 and $L\alpha''$ in the formula for receiving-end impedance.

Taking the above example, loading the line brought the real attenuation-constant α'_1 down from 0.071 to 0.012 or nearly six times. Other things being equal, therefore, the possible range of transmission should have been increased nearly six times. Experiments indicate, however, only a four-fold increase in range, or with "terminal tapers" nearly five-fold,* and the discrepancy may be accounted for by the increase in z_0.

Effect of Dielectric Losses on Loading.

If we denote the conductor impedance $r + j\,l\,\omega$ by the vector $z_c \underline{|\theta_c}$, it is evident that

$$z_c^2 = r^2 + l^2\omega^2 \qquad \left(\frac{\text{ohm}}{\text{kilometer}}\right)^2 \qquad . \quad . \quad . \quad (89)$$

and $$\tan\theta_c = \frac{l\,\omega}{r} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (90)$$

The ratio of the reactance $l\,\omega$ to the conductor-resistance r at the angular velocity ω, may be called the reactance-factor of the conductor, and it is equal to the tangent of the angle of the vector z_c.

Again, if we denote the dielectric admittance $g + jc\omega$ by the vector $y_d \underline{|\theta_d}$, it is evident that

$$y_d^2 = g^2 + c^2\omega^2 \qquad \left(\frac{\text{mho}}{\text{kilometre}}\right)^2 \qquad . \quad . \quad . \quad (91)$$

and $$\tan\theta_d = \frac{c\,\omega}{g} \qquad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (92)$$

* Hayes, loc. cit., p. 643.

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The ratio of the susceptance $c\omega$ to the dielectric conductance g, at the angular velocity ω, may be called the susceptance-factor of the insulator, and it is equal to the tangent of the angle of the vector y_d.

Loading a circuit obviously increases the angle θ_c and its tangent the reactance factor. This is particularly marked in the case of telephone cables, in which the unloaded conductor may have a reactance factor of only about 0.03 and an angle of $\theta_c = 1°.40'$ say. On the other hand, if there be no waste of energy in the dielectric, either by leakage or by hysteresis, $g = 0$ and $\theta_d = 90°$, or the susceptance factor is infinite. In such a case we may theoretically diminish the real-attenuation-constant a_1 to any extent by increasing the loading or inductance per kilometre, assumed smooth, although the benefit obtainable will be limited by the extra r'' and the increase in z_0. But if there be appreciable waste of energy in the dielectric; so that the angle θ_d falls distinctly below 90°, then it may readily be demonstrated that it is useless to load the conductor beyond the limit at which the conductor reactance-factor is equal to the dielectric susceptance-factor; or $\theta_c = \theta_d$. In other words the real attenuation-constant a_1 reaches a minimum when:—

$$\theta_c = \theta_d \qquad \text{degrees or radians} \qquad (93)$$

or

$$\frac{l}{r} = \frac{c}{g} \qquad \text{seconds} \qquad (94)$$

By loading beyond this limit, we continue to increase a and z_0 without diminishing a_1 and so add to the receiving-end impedance instead of reducing it.

When the conditions of (93) and (94) are realized, the angle of $a = \theta_c = \theta_d$ and the angle of $z_0 = 0°$, or the initial sending-end impedance is reactanceless.

As an example, see Table XIII, consider the first type of paper cable analyzed in Table XII, having $r = 54.57$, $l = 3.107 \times 10^{-4}$, $g = 0$ and $c = 8.7 \times 10^{-8}$, in kilometre units. Here $\theta_c = 1°.38'$ and $\theta_d = 90°$. If we load each wire of this circuit with 47.15 millihenrys per kilometre, $l + l'' = 47.46 \times 10^{-3}$ and $(l + l'')\,\omega =$ 237.3 ohms per kilometre. $\theta_c = 77°.03'$ and a_1 is reduced from 0.107,4 to 0.036,7 per kilometre. If we increase the loading to a total smooth reactance of 300 ohms per kilometre, a_1 is again

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reduced to 0.0327 per kilometre, and so on. But if instead of $g = 0$ we introduce loss of energy in the insulator either by leakage or hysteresis, to the extent $g = 10^{-4}$ mho-per-kilometre, the unloaded real attenuation-constant is only slightly altered; namely to $\alpha_1 = 0.1208$ per kilometre. The angle θ_d is now 77°.03′. Loading the conductor as before, will now reduce the real attenuation-constant until $(l + l'')\ \omega = 237.3$ ohms per kilometre, when θ_c reaches the magnitude of θ_d. Here α_1 reaches the minimum $\alpha_1 = 0.074,16$ per kilometre. If we increase the loading to 300 ohms reactance per kilometre, as before, we make the conditions worse, for α_1 fails to diminish; although z_0 rises.

From such considerations it follows that a high degree of insulation and freedom from hysteretic waste is necessary in the dielectric of a circuit that has to be heavily loaded, and leakage or hysteretic loss which would be insignificant in effect upon an unloaded line may be very prejudicial after the line has been loaded.

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Table XIII.

Showing the effect of waste in the dielectric upon the loading of a circuit.

g mhos / k. m.	$c\omega$ mhos$\times 10^{-4}$ / k. m.	r ohms / k. m.	l henry$\times 10^{-3}$ / k. m.	l'' extra henry$\times 10^{-3}$ / k. m.	$l+l''$ total henry$\times 10^{-3}$ / k. m.	z_c ohms / k. m.	θ_c	y_d mhos$\times 10^{-4}$ / k. m.	θ_d	a per k. m.		z_0 ohms		a_2 per k. m.	a_1 per k. m.
0	4.35	54.57	0.31	0	0.31	54.6	1°.38′	4.35	90°	0.1541	45°.49′	354.3	44°.11′	0.1107	0.1074
0	4.35	54.57	0.31	47.15	47.46	243.5	77°.03′	4.35	90°	0.3254	83°.32′	748.2	6°.29′	0.3233	0.0367
0	4.35	54.57	0.31	59.69	60.00	304.9	79°.42′	4.35	90°	0.3642	84°.51′	837.2	5°.9′	0.3627	0.0327
0	4.35	54.57	0.31	199.69	200.00	1001.5	86°.53′	4.35	90°	0.66	88°.27′	1,517	1°.33′	0.6596	0.0179
10^{-4}	4.35	54.57	0.31	0	0.31	54.6	1°.38′	4.463	77°.03′	0.1561	39°.30′	349.7	37°.43′	0.0990	0.1208
10^{-4}	4.35	54.57	0.31	47.15	47.46	243.5	77°.03′	4.463	77°.03′	0.3297	77°.03′	738.7	0°.	0.3213	0.0742
10^{-4}	4.35	54.57	0.31	59.69	60.0	314.9	79°.42′	4.463	77°.03′	0.3689	78°.22′	826.6	1°.19′	0.3613	0.0744
10^{-4}	4.35	54.57	0.31	199.69	200.0	1001.5	86°.53′	4.463	77°.03′	0.6686	81°.58′	1,471	4°.55′	0.6620	0.0935

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Appendix.

Graphical Constructions.

It is important to acquire concrete conceptions of hyperbolic functions, when dealing with the applications of those functions to alternating-current circuits. In order to obtain such conceptions, reference may first be made to the elementary trigonometrical functions, and then to the following constructions which appear to be new.

In Fig. 14, the radius vector OE makes a circular angle AOE with the initial line OA, which, for convenience, is chosen of unit length. The value of this angle in radian measure is known to be numerically equal to twice the area of the circular sector AOE, or to the shaded area OEAE′. Thus, if the angle AOE′ is one radian, as indicated in the figure, the area OEAE′ will be one square centimetre if OA is one centimetre long.

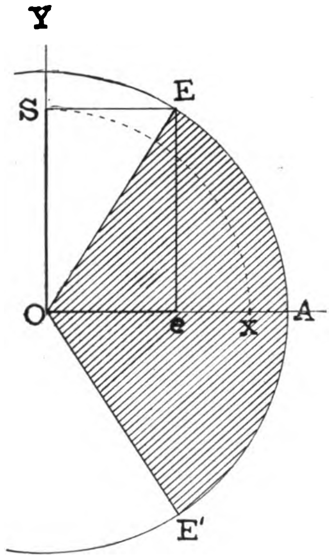

Fig. 14.—Circular Sines and Cosines of Real Angles. Hyperbolic Sines and Cosines of Imaginary Angles.

The cosine of this angle is Oe, the projection of OE upon the initial line. The sine is OS, the projection of OE upon the Y axis, followed by a clockwise, or $-j$, rotation of 90° upon the X axis; so that Oe = cos AOE and Ox = sin AOE.

Similarly, in Fig. 15, the radius vector OE of varying length, makes a hyperbolic angle with the initial line OA, which, for convenience, is chosen of unit length. The extremity E of the vector OE describes a rectangular hyperbola E′AE. The value of the hyperbolic angle in radian measure is known to be numerically equal to twice the area of the hyper-

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bolic sector AOE, or to the shaded area OE AE′. Thus, if the hyperbolic angle AOE is one hyp. radian, as indicated in the Figure, the shaded area OE AE′ will be one square centimetre, if OA is one centimetre long. This hyperbolic angle must be carefully distinguished from the circular angle AOE of Fig. 15, which

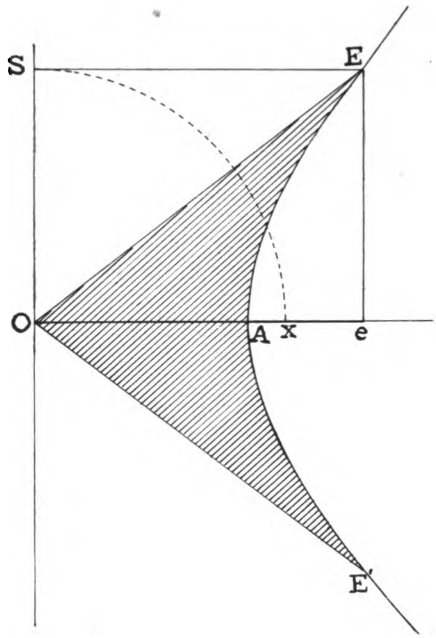

FIG. 15.— Hyberbolic Sines and Cosines of Real Angles.

measures approximately 37°.17′.30″, or 0.651 circular radian; whereas it corresponds to 1 hyperbolic radian.

The hyp. cosine of the hyp. angle AOE is Oe, the projection of OE upon the initial line. The hyp. sine is the projection OS of OE upon the Y axis, followed by a clockwise, or -j, rotation of 90° upon the X axis; so that we have Oe = cosh AOE, and Ox = sinh AOE.

Again the hyp. cosine of an imaginary hyp. angle, or an angle of the type $j\,y$, is obtained by marking off in Fig. 14, a circular angle of y radians, such as AOE. The hyp. cosine of $j\,y$ will be

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Oe, the projection of OE on the X axis, and the hyp. sine of $j\,y$ will be the projection of OE on the Y axis (without any subsequent rotation). Consequently, $\cosh j1 = Oe = 0.5403$ and $\sinh j1 = OS = j\,0.841$.

Constructions for cosh $(x + j\,y)$ and cosh^{-1} $(x + j\,y)$.

If now we seek the hyp. cosine of a complex angle of the type $(x + j\,y)$, we first draw a circular angle AOB, Fig. 16, of y circular

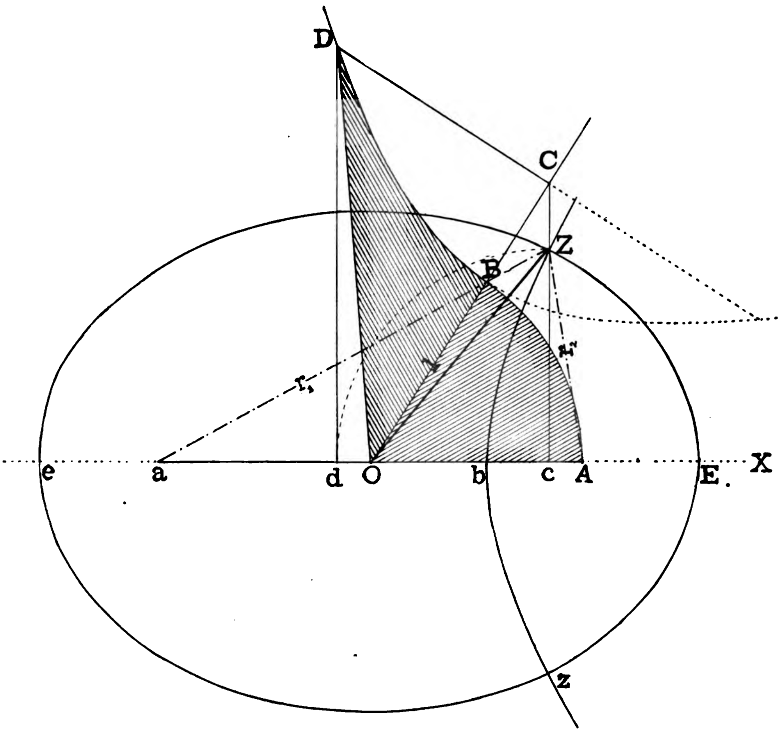

FIG. 16.— Graphical Constructions for Cosh $(x \pm jy)$ and Cosh^{-1} $(x \pm jy)$.

radians, and then, on the line OBC as base, draw a hyperbolic angle BOD, of x hyperbolic radians. We then let fall a perpendicular DC, from D upon line OB. The projection cd of CD

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upon the initial line, followed by a clockwise or $-j$ rotation through 90°, about the point c, will make $cZ = cd$, and OZ will then be the required hyp. cosine; or $\cosh\ (x + j\,y) = Oc + j\,c\,Z = OZ \ \underline{|\tan^{-1} \frac{cZ}{Oc}}$. In the case represented in the Figure, $x = 1$ and $y = 1$; so that $\cosh\ (1 + j\,1) = OZ = 0.834 + j\,0.989 = 1.293\ \underline{|49°.52'}$.

If the angle x is maintained constant, and the imaginary angle $j\,y$ is varied, the locus of OZ, the hyp. cosine, will be the ellipse Z e z E, whose foci are at a and A, both at unit distance from O, on the initial line OX. Again, if the imaginary part jy of the angle is maintained constant, and the real component x is varied, the locus of OZ, the hyp. cosine, will be the hyperbola Z bz, which is confocal with the ellipse just referred to. The formal relation is

$$\cosh\ (x \pm j\,y) = \cosh x \cos y \pm j \sinh x \sin y = a \pm j\,\beta \quad . \quad (95)$$
$$= \sqrt{\cosh^2 x - \sin^2 y}\ \underline{|\tan^{-1}\ (\tanh x \tan y)}$$

Reciprocally, if we have a certain vector $OZ = a + j\,\beta$ say, and we desire to know the angle of which it is the hyp. cosine; so that $x + j\,y = \cosh^{-1}\ (a + j\,\beta)$, we infer that the hyp. cosine of x is equal to OE, the semi-axis major of the ellipse through Z, or $\cosh x = OE$, and that the hyp. cosine of $j\,y$ is equal to Ob, the semi-axis of the hyperbola through Z, or $\cosh j\,y = O\,b$. It only remains then to determine the semi-axes OE and Ob, in order to solve the problem. These semi-axes are determined by the radii r_1 and r_2 from the joint foci of the curves, under the conditions $\frac{r_1 + r_2}{2} = OE$ and $\frac{r_1 - r_2}{2} = Ob$.

Expressed formally, we have:—

$$\cosh^{-1}\ (a + j\,\beta) = \cosh^{-1} \left\{ \frac{\sqrt{(1+\alpha)^2 + \beta^2} + \sqrt{(1-\alpha)^2 + \beta^2}}{2} \right\}$$
$$\pm j \cos^{-1} \left\{ \frac{\sqrt{(1+\alpha)^2 + \beta^2} - \sqrt{(1-\alpha)^2 + \beta^2}}{2} \right\} \quad (96)$$
$$= x \pm j\,y$$

In the case represented by Fig. 16, $a = 1$ and $j\,\beta = 1$; so that $\cosh^{-1} OZ = \cosh^{-1}\ (1.293\ \underline{|49°.52'}) = \cosh^{-1}\ (0.834 + j\,0.989)$ $= \cosh^{-1} OE + j \cos^{-1} Ob$

$$= \cosh^{-1} 1.543 + j \cos^{-1} 0.540 = 1 + j\,1.$$

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Constructions for sinh $(x + jy)$ and sinh^{-1} $(x + jy)$.

In order to construct the hyp. sine of a complex angle $x + jy$ draw an angle AOB, Fig. 17, of y circular radians. On the line OBC as base, with OB $= 1$, draw the rectangular hyperbola*

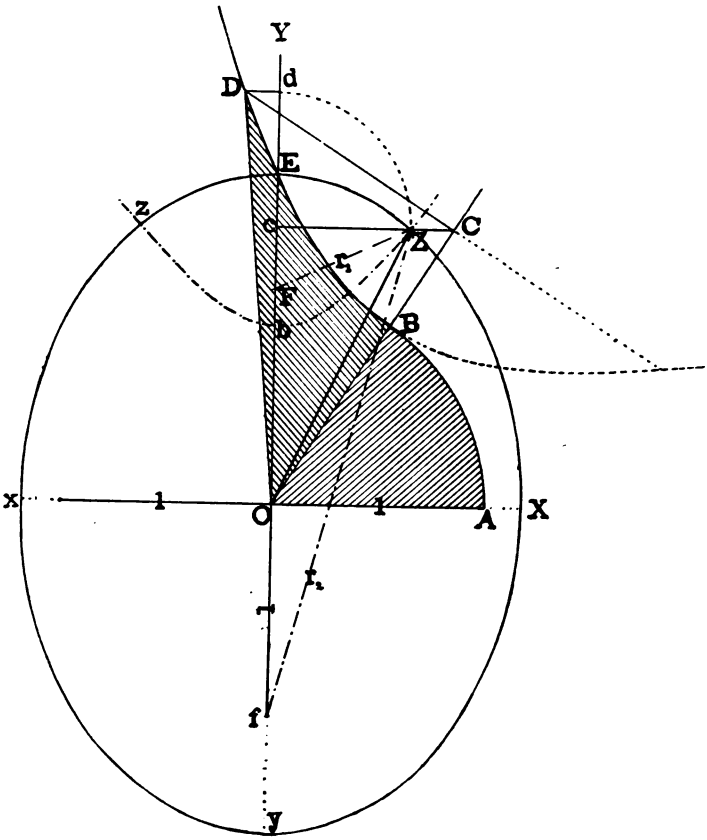

FIG. 17.— Graphical Constructions for Sinh $(x \pm jy)$ and Sinh^{-1} $(x \pm jy)$.

BED, and mark off on it the hyp. angle DOB $= x$ hyp. radians as previously defined. Project the point D perpendicularly upon the

* A celluloid protractor of the form ABD Figs. 16 and 17 with the arc AB marked off in circular radians, up to π say, and the arc BD marked off in hyperbolic radians, up to 1.2 say, will be found useful in these constructions.

base OB at C, and project both the points D and C upon the Y axis perpendicularly at d and c respectively. With centre c, rotate cd clockwise, or in the negative direction, through 90° to Z; so that $cZ = -j\,cd$. Then OZ will be the required vector hyp. sine of $x + j\,y$. For it is evident that the formal relation is satisfied:—

$$\sinh (x + j\,y) = \sinh x \cos y + j \cosh x \sin y = a + j\,\beta = cZ + j\,Oc$$

$$= \sqrt{\sinh^2 x + \sin^2 y} \;\underline{|\tan^{-1} (\coth x \tan y)} \quad . \quad . \quad (97)$$

If the real component x is varied, leaving y constant, the locus of OZ will be the hyperbola $Z\,b\,z$. If, on the other hand, the imaginary component $j\,y$ is varied, leaving x unchanged, the locus of OZ will be the ellipse XE xy. Both this ellipse and the hyperbola $Z\,b\,z$ have foci at F and f, points situated at unit distance from O on the Y axis.

In the case represented in Fig. 17, $x = 1$ and $y = 1$; so that $OZ = 0.635 + j\,1.2985 = 1.446 \;\underline{|63^\circ.57'}$.

Reciprocally, if we have a certain vector $OZ = a + j\,\beta$ say, and we desire to know the angle of which it is the hyp. sine; so that $x + j\,y = \sinh^{-1} (a + j\,\beta)$, we infer that the hyp. cosine of x is equal to OE, the semi-axis major of the ellipse through Z, having F and f as foci, or $\cosh x = OE$; also that the hyp. sine of $j\,y$ is equal to Ob, the semi-axis of the hyperbola $Z\,b\,z$ running through Z, with foci at F and f, or $\sinh j\,y = O\,b$; $\sin y = O\,b$ numerically. It only remains to determine the semi-axes OE and O b, in order to solve the problem. These semi-axes are determined by the radii r_1 and r_2 to the point Z from the joint foci F f, through the conditions $\frac{r_1 + r_2}{2} = OE$, and $\frac{r_1 - r_2}{2} = \pm\,Ob$.

Expressed formally, we have:—

$$\sinh^{-1} (a \pm j\,\beta) = \cosh^{-1} \left\{ \frac{\sqrt{(1 + \beta)^2 + a^2} + \sqrt{(1 - \beta)^2 + a^2}}{2} \right\}$$

$$\pm j \sin^{-1} \left\{ \frac{\sqrt{(1 + \beta)^2 + a^2} - \sqrt{(1 - \beta)^2 + a^2}}{2} \right\} \quad (98)$$

$$= x \pm j\,y.$$

In the case represented by Fig. 17, $a = 0.635$ and $\beta = 1.2985$; so that $\sinh^{-1} (a + j\,\beta) = \cosh^{-1} 1.543 + j \sin^{-1} 0.841 = 1 + j\,1$ $= 1.414 \;\underline{|45^\circ}$.

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Constructions for tanh $(x + j\,y)$ and $tanh^{-1}$ $(x + j\,y)$.

In order to construct the hyp. tangent of a complex angle $(x + j\,y)$, draw two coordinate axes XO x and YOy, Fig. 18. Mark off two points A and B on the X axis, each at unit distance from

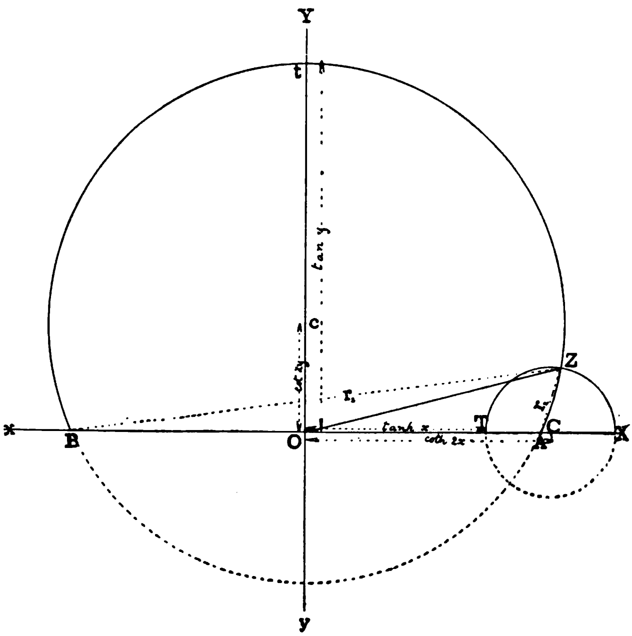

FIG. 18.— Graphical Constructions for tanh $(x + jy)$ and tanh^{-1} $(x + jy)$

the origin O. Lay off a length OT on the X axis equal to tanh x, and likewise a length O t on the Y axis equal to tanh $y = j$ tan y; that is O t = tan y. Draw a circle through the three points A B and t. The center c of this circle will lie on the Y axis at a distance Oc from the origin equal to cot $2\,y$, taking the direction Oy for positive cotangents. Through T draw a circle which shall intersect the circle ABt orthogonally. This circle TZX will have its center at C on the X axis at a distance OC = coth $2\,x$. Join the point of intersection Z of the two circles with the origin by the line OZ. This vector OZ is the required hyp. tangent.

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If the real component x in the complex angle be varied, leaving y unchanged, the vector OZ will move around the circle A t B. If, on the contrary, the imaginary component y be varied, leaving x unchanged, the vector OZ will move around the circle TZX, performing one complete revolution for each π units of increase in y. Expressed formally, we have:—

$$\tanh\ (x \pm j\, y) = \frac{\sinh 2x}{\cosh 2\,x + \cos 2\,y} \pm j \frac{\sin 2\,y}{\cosh 2\,x + \cos 2\,y} \qquad (99)$$

Thus, if $x = 1$ and $y = 1$, $\tanh\ (x + j\, y) = 1.084 + j\, 0.2718 = 1.118\ \underline{|14^\circ.35'}$.

Reciprocally, if we have a certain vector $OZ = a + j\, \beta$, say, and we desire to know the angle of which it is the hyp. tangent; so that $x + j\, y = \tanh^{-1}\ (a + j\, \beta)$, we mark off the unit-distance points A and B on the X axis, and draw the lines BZ and AZ, marked r_1 and r_2 respectively in Fig. 18. These radii vectores include a constant angle AZB as we move around the circle A t B of constant y and their ratio r_1/r_2 is constant as we move around the circle TZX of constant x. Consequently the angle AZB between the radii determines the value of y and their ratio determines the value of x. A perpendicular bisector to r_2 will intersect the Y axis in the center c of circle A t B, and with center c and radius cZ this circle may be drawn thus prescribing Ot. A bisector to the angle A Z B will intersect the X axis at T and through the points T and Z a circle centered on the X axis can be drawn in the ordinary way. We then have $x = \tanh^{-1}$ OT and $y = \tan^{-1}$ Ot; or expressed formally:—

$$\tanh^{-1} (a \pm j\, \beta) = \tfrac{1}{2} \log_e \sqrt{\frac{(1 + x)^2 + y^2}{(1 - x)^2 + y^2}}$$
$$\pm j \left\{ \frac{\pi - \tan^{-1}\left(\frac{1 + x}{\pm y}\right) - \tan^{-1}\left(\frac{1 - x}{\pm y}\right)}{2} \right\} \qquad . \qquad (100)$$
$$= x \pm j\, y$$

Thus if $a = 1.084$ and $\beta = 0.2718$, $\tanh^{-1}\ (a + j\, \beta) = 1 + j\, 1 = 1.414\ \underline{|45^\circ}$.

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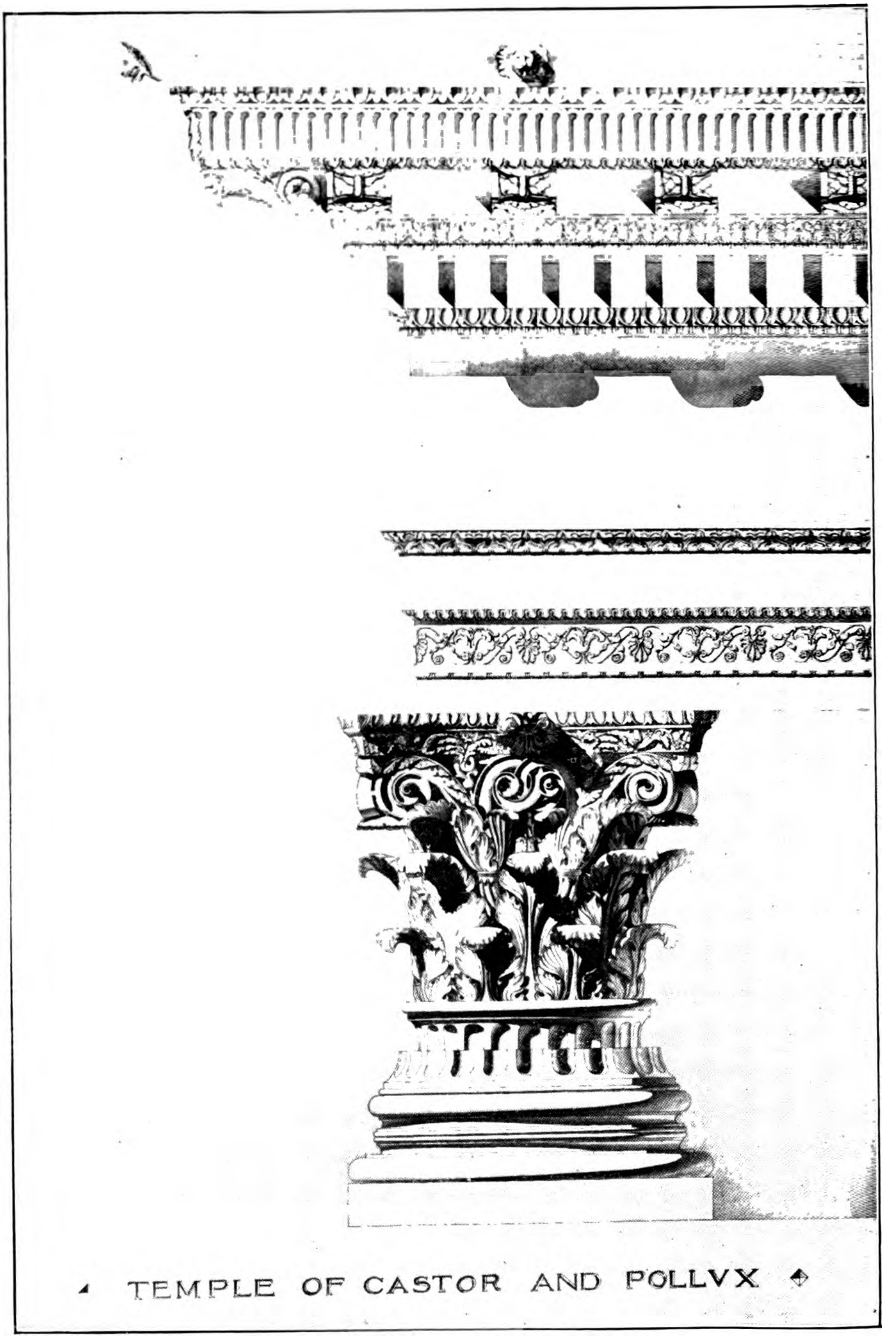

A Corinthian Order.
W. G. Thomas. First-Year Work.

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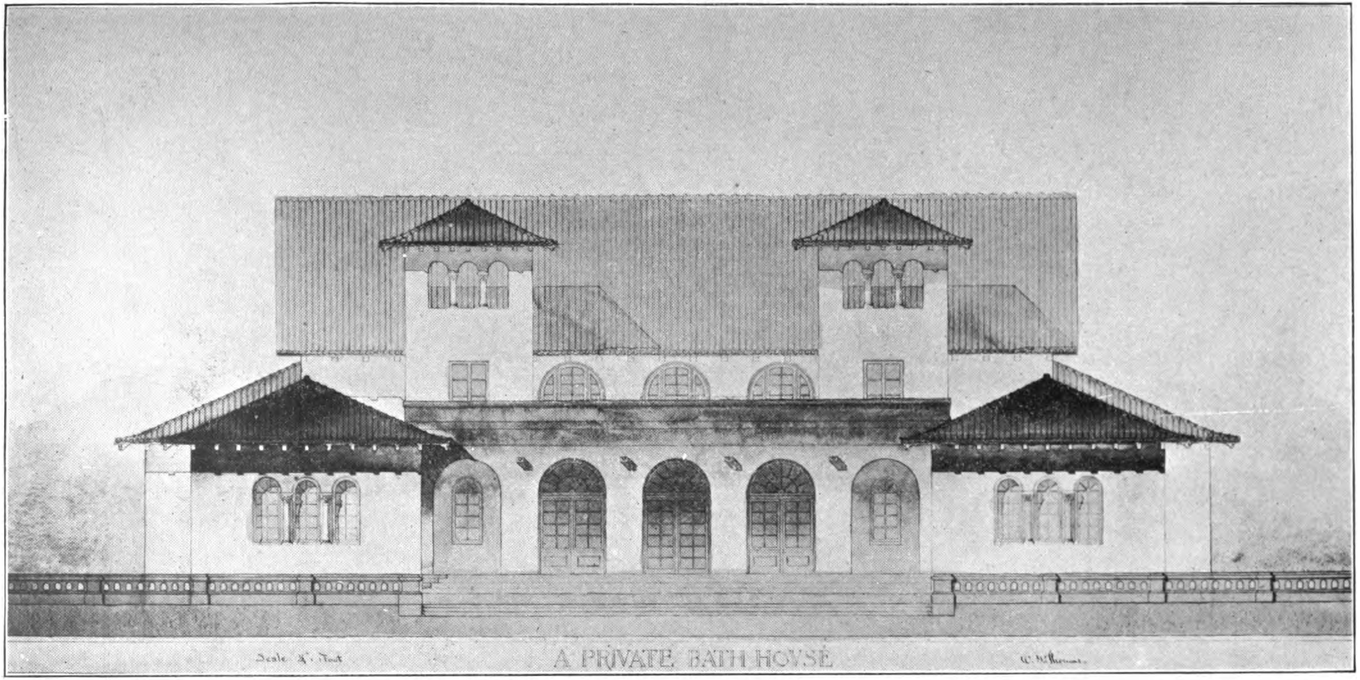

W. G. Thomas. A PRIVATE BATH HOUSE. Second-Year Work.

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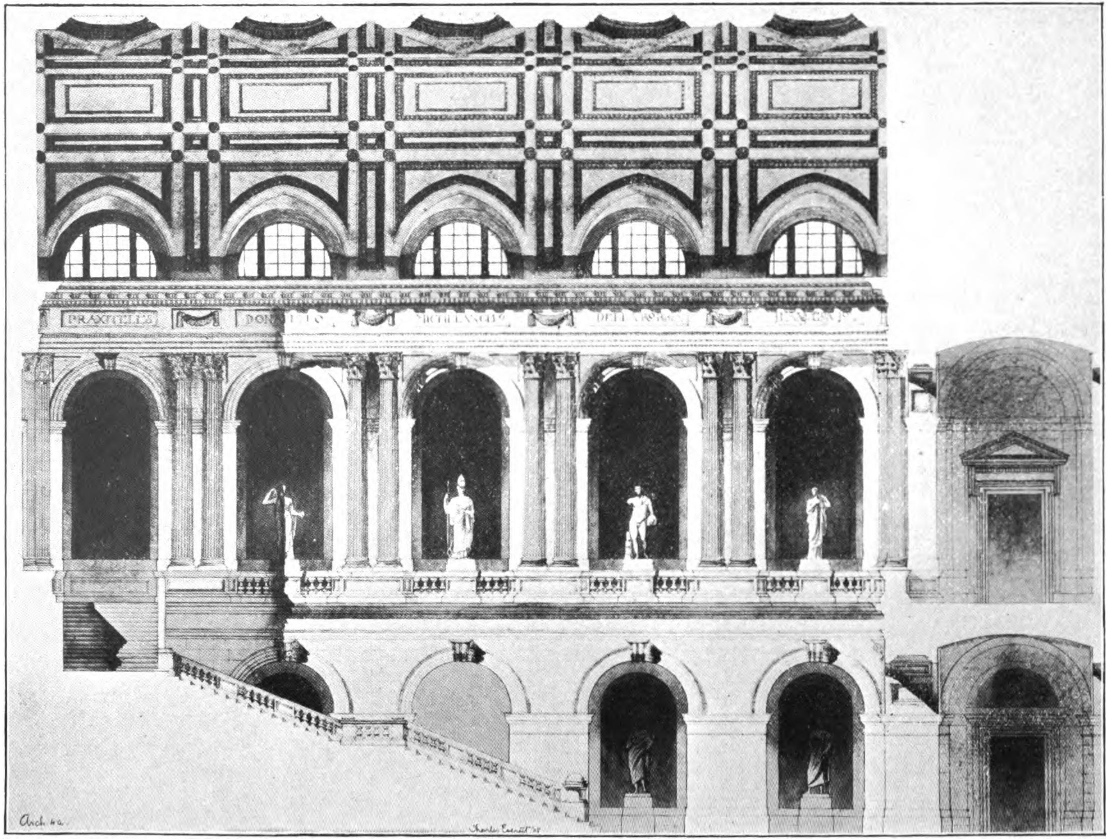

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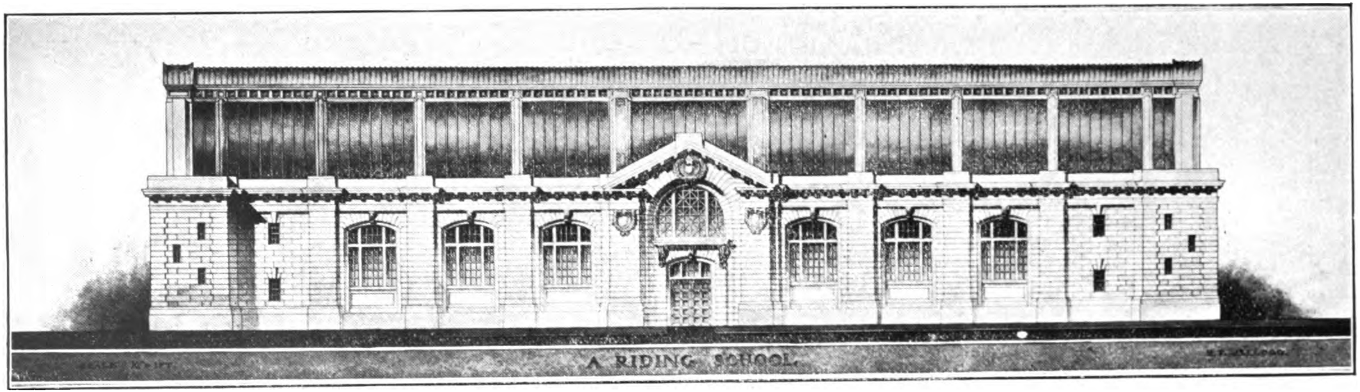

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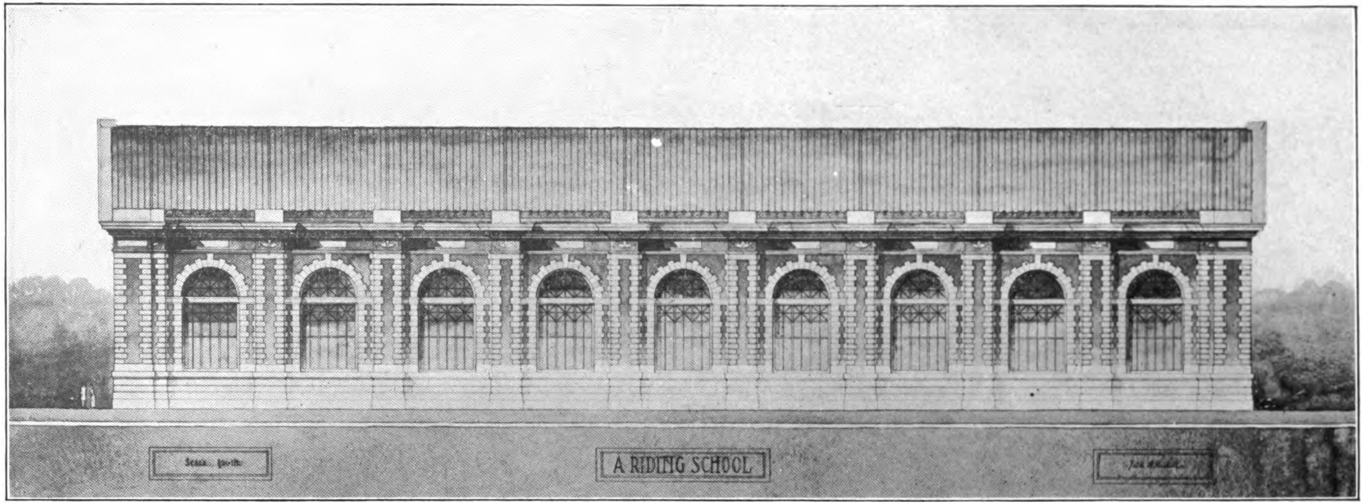

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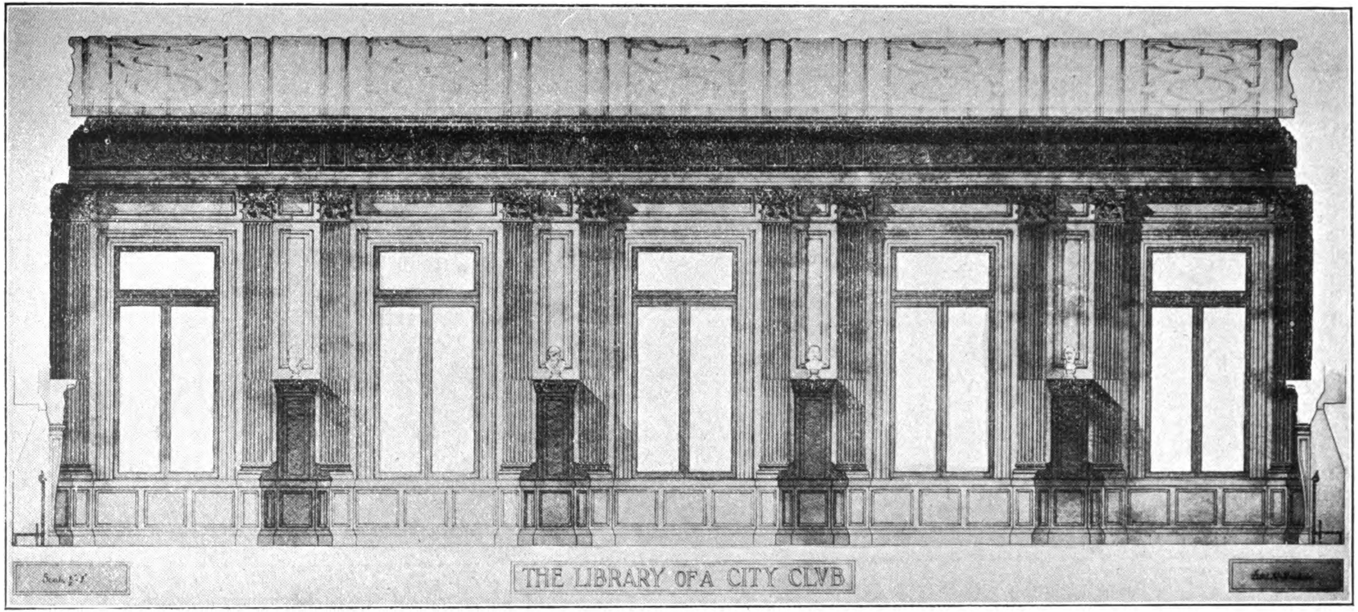

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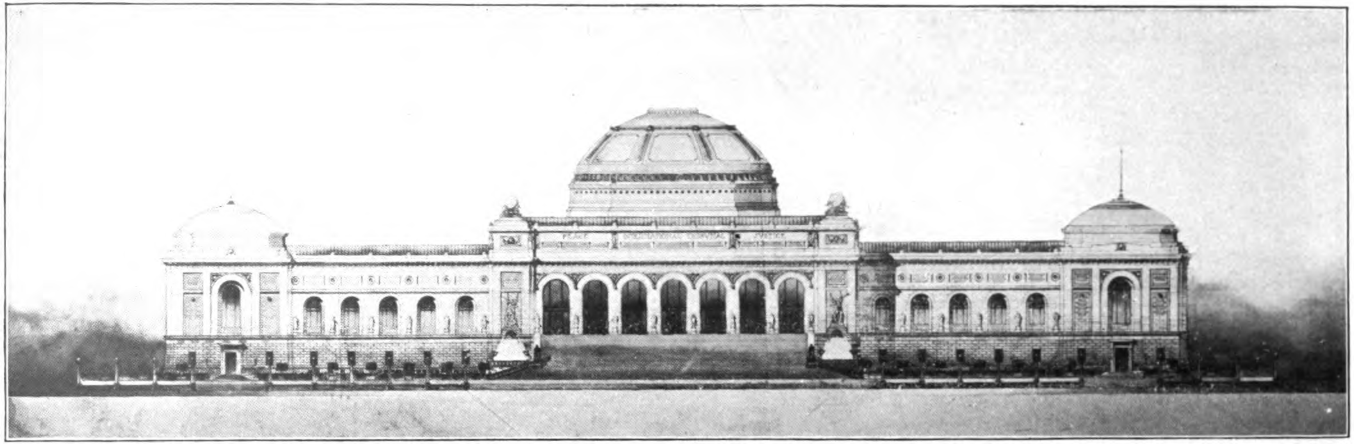

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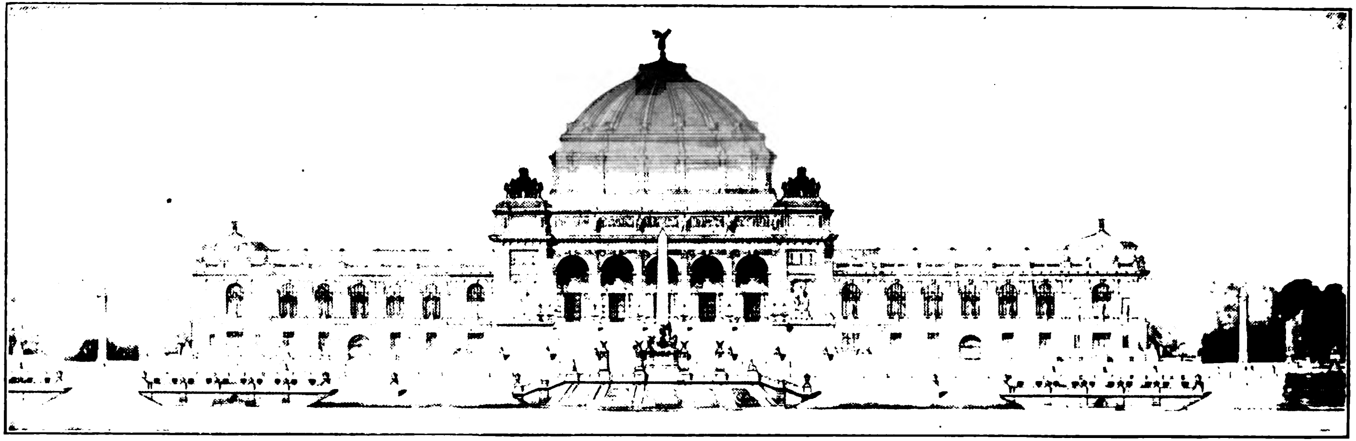

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A QUARTERLY

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Editorial.

We take pleasure in announcing the election of the following to the Board of Editors: W. G. Thomas, Sp., Secretary, Henry L. Lincoln, '07, Assistant Circulation Manager and C. C. Pope, '08, Assistant Business Manager.

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Waterproofing Transmission Rope.

There is a large demand for a first-class waterproofed transmission rope. Of course, the principal use of this rope is on drives exposed to the weather. On such drives, when using single ropes, there is often trouble from the stretching and shrinking of the rope, caused by changes in the weather. Sometimes this trouble is quite serious, the shrinkage of the rope pulling down shafting, or at least causing hot bearing. On account of this stretch and shrinkage, outdoor drives are usually made on the American system, using a tension carriage, which takes care of the variation in length. This increases the cost of the drive, and the rope does not last long because it is affected so much by dampness.

Cotton and other mills, to which additions are made, usually have the new buildings at a short distance from the main plant, and drive across the open space by means of ropes. In designing new plants it is advisable, in many cases, to have the shafts project through the walls and drive along the outside of the buildings with ropes. This saves space inside, especially head room, as the shafting can be placed higher and large sheaves can be used for driving. The lighting will also be better. Waterproofed rope makes such an arrangement satisfactory.

There is also quite a demand from cotton gins and cotton oil mills for a transmission rope which will not be affected by the hot, damp summer climate. There is usually a great deal of trouble in these mills when starting up in the fall, as the ropes are left on the drives during the summer and are weakened by the causes mentioned. On rice plantations, it is becoming quite a usual thing to drive the centrifugal pumps by means of ropes, which, of course, are exposed to a great deal of dampness, and are frequently wetted. The same is true of ropes used to transmit power from water wheels.

In paper and pulp mills there is also a demand for waterproofed ropes, as belting will not stand extreme humidity of the air.

The American Manufacturing Company, 65 Wall Street, New York has been experimenting for a long time to make a water-

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proofed rope, and the article now being introduced is the result of many experiments, carried out under the supervision of J. B. Upright, Superintendent of its Brooklyn mills. In testing this rope, it has been hung in the East River for long intervals, to determine its waterproof qualities, and has been run on the company's outdoor drives over a year. One of these drives consists of ten 1-3/4 inch ropes, running almost the full length of the roof of a four story building 225 feet long, which is on the water front of the East River. After running for some time, the rope becomes perfectly smooth and highly polished. The waterproofing fills the jaw of the rope, preventing the accumulation of moisture in the crevices and this waterproofing being elastic remains in place, even while the rope is running around the sheaves.

The waterproofing adds about 2 per cent to the weight of the rope, which lasts as long as standard transmission rope, for in addition to the waterproofing it is thoroughly lubricated internally with flake graphite. The ropes run on the roof drive show no more wear than ropes in the mills which have run for the same length of time, under the most favorable conditions. On its machines the American Manufacturing Company can make coils of transmission rope 10,000 feet long without a splice.

Exchanges.

The JOURNAL wishes to acknowledge the following Exchanges:

Proceedings of the American Institute of Electrical Engineers, The Sibley Journal of Engineering, Journal of the Western Society of Engineers, The Journal of the Worcester Polytechnic Institute, The Journal of the Franklin Institute, Proceedings of the American Society of Civil Engineers, The Polytechnic, The Architect & Engineer of California, The Electric Journal, The Bulletin, Stevens Institute Indicator, The Iowa Engineer, Revue de L'Ingénieur et Index Technique, The Michigan Technic, The Wisconsin Engineer, Technical World Magazine, Journal of the Association of Engineering Societies.

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Graduate Notes.

Kilburn E. Adams, '03, is mechanical engineer and supervisor of storehouses at Sayles Bleacheries, Saylesville, R. I. Address, 69 Mt. Vernon St., No. Cambridge, Mass.

D. C. Campbell, '02, is employed as mine manager in Joplin, Mo. Address, 607 Sargeant Ave., Joplin, Mo.

Davenport Brown, '02, was compelled, last March, to give up active work in mining engineering to assume care of his father's estate.

Philip W. Davis, '95, is engaged in general engineering practice in the office of Charles K. Stearns, 93 Federal St., Boston.

Allan G. McAvity, '03, is with the Canadian Buffalo Forge Co. L't'd. We have a copy of his paper on the "Heating and Ventilation of St. Paul's Hospital, Montreal, Quebec," which was read before the Canadian Society of Civil Engineers. In it he describes an interesting method, by which the humidity of the air is maintained constant by the use of a number of spray nozzles through which water is forced under pressure. Address, Montreal, Que.

As a result of recent examinations held by the Municipal Civil Service Commission the following men were placed upon the Board of Water Supply, City of New York.

R. W. Greenlaw,	'02,	Asst.	Engineer	2nd	Grade
J. P. H. Perry,	'03,	"	"	"	"
J. P. Hogan,	'03,	"	"	"	"
W. Hanavan,	'03,	"	"	"	"
Donald Howes,	'03,	"	"	1st	"
J. M. Sanborn,	'99,	"	"	3rd	"
Emerson,	'04,	"	"	1st	"
Eliot Smith,	'04,	"	"	2nd	"

The higher numbers represent the higher grades.

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This "Board of Water Supply" has charge of the new project of building the greatest dam and reservoir ever known, and also of 100 miles of large aquiduct of 500,000,000 gallons per day capacity. The water is to be taken from the Catskill Mts., and is calculated to give New York a supply adequate up to 1925.

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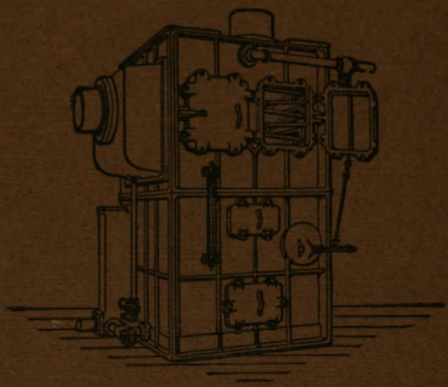

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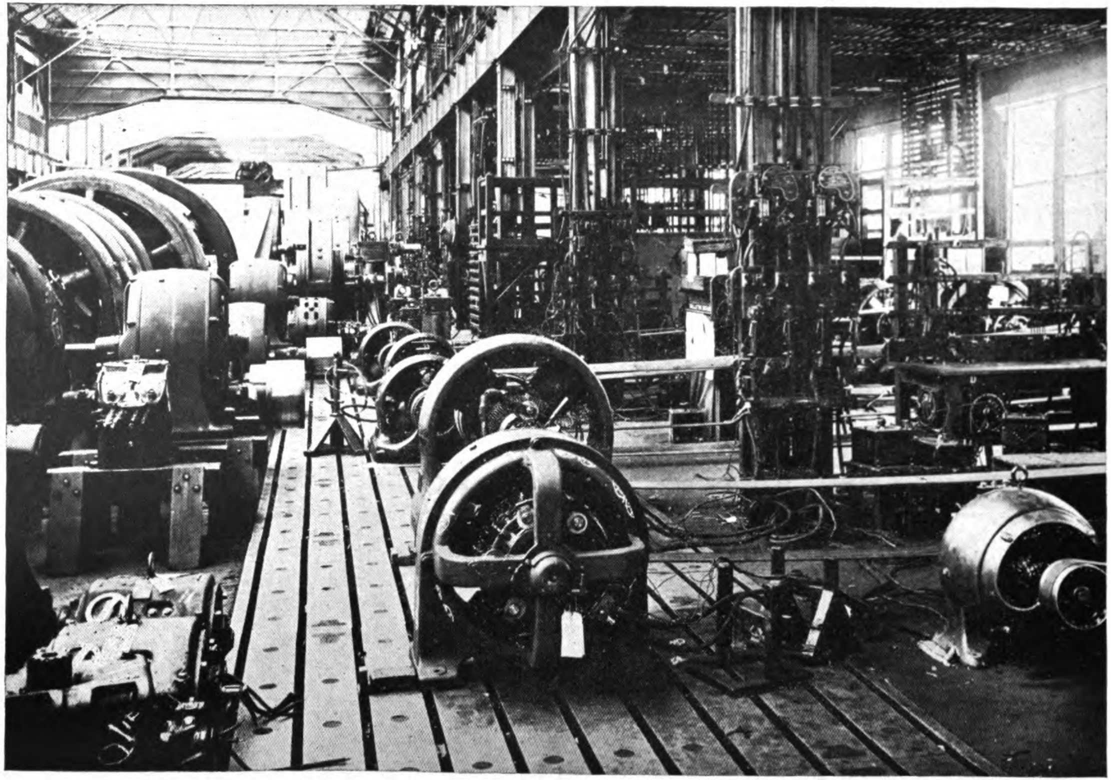

View in Small Motor Testing Department, Building No. 11,
General Electric Co., Schenectady Works.

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VOL. V JUNE, 1906 NO. 2

FACTORY TESTING OF ELECTRICAL MACHINERY.

F. PARKMAN COFFIN.

ELECTRICAL machinery generally requires thorough testing, before leaving the factory, to discover all weaknesses and faults while they may easily be remedied. Otherwise such faults may be the cause of much delay and dissatisfaction if not remedied before the machine reaches the customer.

The General Electric Co. maintains a special department for testing apparatus, both at Lynn and at Schenectady. These departments employ a large number of students, apprentices and mechanics. At the Schenectady Works about 480 students are employed in the Testing Department, 80% of them being technical school graduates who are taking this work as a sort of post-graduate course. Nearly every technical school in the United States is represented as well as a number of foreign schools. All men applying for positions with the General Electric Co., in its Engineering, Construction and Commercial Departments, are required to serve their apprenticeship in "the test." The usual time spent in the testing department is from one and a half to two years, and the men are moved about among the various sub-departments of "the test" handling different classes of work.

All of the electrical testing is done by the students, working under the foremen of the various sub-departments who are students also, but are spending from six months to a year, or more, in charge of one department. All the temporary wiring is done by students

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while much of the heavy mechanical work, connected with the setting up of machines and preparing them for test, is done by the mechanics and laborers employed in the department.

The results of the tests on each machine are recorded on special test record sheets and handed in to the Engineering Department where the tests must be approved before the machine can be shipped. The testing records are then bound and filed. The tests have a double value: first,— as a trying out of individual machines to discover faults in time to remedy them, and second, to accumulate data showing the behavior of each line of machines for future use in designing.

The factories are supplied with power by two separate circuits, one, a 500 volt metallic circuit and the other, a 125 and 250 volt three-wire system with grounded neutral. Special feeders from these circuits supply the testing departments located in the various buildings.

The principal source of power is the large hydo-electric plant of the Hudson River Power Company located at Spiers Falls, some forty miles north of Schenectady. The transmission line contains two special 3-phase circuits for the power used in Schenectady and vicinity. The normal load on these two circuits is 6000 kilowatts at 30,000 volts, 40 cycles. This load is kept fairly constant by the General Electric Company's local steam power plants which supply all excess load coming on at various times during the day. One of these plants contains four 1500 kilowatt steam turbo-alternators which are held in reserve for emergencies, when they can be thrown in parallel with Spiers Falls. Steam is always kept on several boilers for various uses about the works, including the testing of steam turbines and the heating of buildings in winter. This station also contains one 2000 kilowatt, 25 cycle turbo-alternator to furnish power for special testing purposes; usually for the New York Central locomotive testing track.

A second steam power station contains three 1200 kilowatt, direct current, engine-driven generators which supply power directly to the shop circuits, running in parallel with a number of rotary converters receiving power from the Spiers Falls line. Both generators and converters have double commutators with

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independent, 250 volt, armature windings. These may be connected in series or parallel so that any machine may be run on either shop circuit at 250 or 500 volts. Several older and smaller machines are held in reserve. The voltage is controlled by a Tyrril regulator at Spiers Falls, and owing to the constant load on the line, the voltage on the D. C. bus-bars at the General Electric power station does not vary more than one per cent. The voltage held at the bus-bars is normally about 265 and 530 volts in order to allow for drop in the direct-current feeders. The transformers for the rotary converters are Y-connected, and the 250 volt neutral feeder is brought in to the neutral point of the transformers.

The Schenectady Railway and Illuminating Companies are fed from the Spiers Falls line, so that the General Electric Company's reserve capacity is at their service in case of a failure of the line. In winter the steam engines operate non-condensing, the exhaust steam being used to heat the factories.

Thus, we see that the power used for testing purposes is drawn from an ample supply, and it is therefore possible to test many of the larger machines more thoroughly than if the power supply were more limited. The most important test on electrical machines is the heat run. There are two general methods of making heat runs: First, full load runs with both normal voltage and normal current. Second, compromise heat runs in which two separate runs are made; one on open circuit with about 10% above normal voltage on the machine; and another on short circuit with about 20% over normal current flowing. Small motors which are built in large numbers from the same design do not all need regular heat runs, provided a certain proportion of each type are so tested. Otherwise, full load heat runs are given, when possible, to all machines except the largest. Generators up to 500 kilowatts capacity can be loaded directly on water rheostats, but the "pumping-back" method of loading is preferred when the necessary apparatus is available.

It is usually impracticable to load generators by the "pumping-back" method except in the case of some of the larger machines when there is a similar machine available to "pump-back" on.

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Generators up to 200 kilowatts capacity are usually loaded directly upon water rheostats which dissipate all the energy, the complication and use of extra apparatus involved in "pumping-back" small generators is not worth the saving in energy. With large machines, however, it is a different matter. Almost all alternators above 200 kilowatts capacity are given compromise heat-runs, being belted to a small shop motor which supplies the losses. Steam turbine driven alternators are assembled with their turbine and are given compromise heat-runs. The 500 kilowatt turbo-alternators (the smallest size built at Schenectady) and all direct current turbine generators are loaded upon water rheostats for a full load heat-run.

Large direct current generators, motors, and rotary converters are loaded by "pumping-back" whenever possible. The German silver series-field shunts are adjusted in the testing department to give the proper degree of compounding under load.

The principal object of the heat run is to determine the maximum temperatures to which all parts of the machine will rise under continuous operation, first, at its rated output and, afterwards, under overloads of 25%, 50%, or whatever the conditions call for. These tests are much more severe than the conditions which the machines will ordinarily meet in service. On direct current dynamos the commutation can be observed under load and the best position for the brushes determined; and on interpolar machines the German silver shunt across the interpolar winding is adjusted to secure the best commutation.

In addition to the heat runs various tests are applied to try the soundness of different parts of the machine. High potential insulation tests are applied both before and after the regular tests, the voltage applied being two or more times the normal voltage of the machine. One side of an alternating current testing circuit is connected to the windings and the other to the frame. Cold and hot resistances are measured before and after the heat run, in order to calculate the rise in temperature by resistance, as a check upon the temperature taken by thermometers. The resistance of the field spools is taken to discover short-circuited turns. These must check within 9% of the average for the machine. The air

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gaps under each pole are measured and must check within 15% of the average. Bearings and end-play are inspected. The various electrical characteristics must be determined, such as field characteristic, core loss curve, and input when running light as a motor. On some alternating current machines there are also regulation, synchronous impedance, and phase characteristics to be taken.

In the case of the smaller railway motors (of 50 horse-power and less) the first 50 machines built are given full load heat runs. After that two motors out of every fifty are so tested, the remainder being run light for half an hour in sets of four. The fields of these four are separately excited by being all connected in series with the "125 volt shop" and a water rheostat. Armature current and speed are then read.

When small railway motors are to be given full load heat runs for one hour, two are coupled together and run as a series motor and a separately excited generator, the generator field being in series with the motor, while its armature is loaded upon a water rheostat.

Railway motors larger than 50 horse-power are usually "pumped back" in pairs as shown in fig. 2. The motor and generator are geared to a counter-shaft driven by the mechanical loss-supply motor (F), a series motor with a water rheostat to control its speed. The armature of a separately excited booster is connected in series with the motor and generator (M & G), these three machines forming a closed circuit independent of the shop circuit. Since both M and G revolve at the same speed and carry the same current their induced electromotive forces are equal and opposite, so that the booster must supply the necessary E. M. F. to circulate the full load current through the machines and overcome all the resistances. All friction and core losses are supplied by the motor F. The machines are started by motor F with the switch S open. When up to normal speed the switch S is closed and the booster field strengthened until normal current flows in the circuit. Normal voltage is held across the motor terminals by varying the speed with the water rheostat and the speed is read at the beginning and end of the run.

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Temperatures on the two machines are taken at the end of the one hour run and average about the same on each with the exception of the generator commutator which is usually 8° or 10° C. higher than the motor commutator. This difference is caused by the poorer commutation of the generator with its brushes on the mechanical neutral point. The current flowing in the armature coil which is short-circuited by the brushes tends to demagnetize the generator field and to magnetize the motor field.

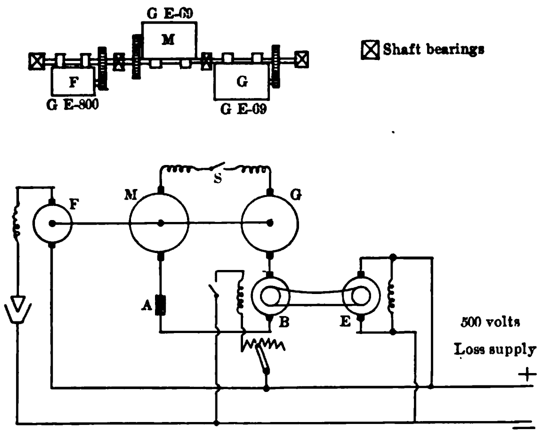

FIG. 2.— PUMP-BACK FOR TWO LARGE RAILWAY MOTORS.

Therefore, the armature reaction will be increased in the generator and decreased in the motor, with the consequence that the generator field coils undergo commutation while in a stronger field than those of the motor. So in judging the results of such a heat run due allowance must be made for the higher temperatures on the generator commutator.

It is usually the case that normal conditions can only be held on one of a pair of dynamos loaded by pumping-back, as one of the machines is running inverted and we can only approximate to the normal conditions in so far as heating is concerned. But the conditions are sufficient for practical purposes.

Shunt motors are usually loaded by the "pumping-back" method, the losses being all supplied electrically, as shown in Fig. 3. The customary method is to belt the motor (M), which is

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under test, to a shop dynamo (G) which runs as a generator connected across the motor terminals. The voltage of the shop circuit is usually a little higher than the rated voltage of the motor under test. So a water rheostat (with plenty of salt) can be put in series with the loss supply to control the voltage (W. R. Fig. 3). A booster is often used, instead of a water rheostat, to hold normal voltage across the motor terminals. This makes a more flexible arrangement as the voltage is easily controlled by the booster field rheostat, raising or lowering the shop voltage as required. A large motor drives a countershaft to which are belted a number of boosters and exciters which can be wired to any switchboard in the department.

The load on the motor under test is controlled by the generator

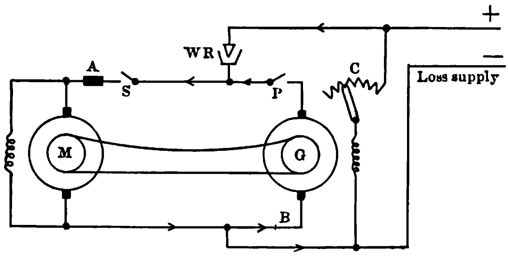

Fig. 3.—Shunt Motor Pump-Back.

field rheostat (C, Fig. 3); weakening the field increases the load and *vice versa.* In starting, the line switch (S) is closed and the water rheostat (W. R.) is slowly cut in by lowering the blade until there is full voltage across the motor. The generator is now being run idle. Its field is excited and strengthened until a voltmeter across the switch P reads zero, when it can be paralleled by closing the switch. The field of G is then further strengthened until full load current flows through the motor and ammeter (A).

To make the shop machines more flexible in "pumping back," and when used as motors to drive generators, many of them have their field winding divided in the middle and a series-parallel switch to connect the two groups of poles in series or multiple. Thus a 500 volt machine may run at 125, 250, or 500 volts, and the fields may be either in series or in multiple on the low voltages.

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The pulley ratios may also be changed to suit the machine it is to run with. In "pumping-back" it is important to excite the generator field from the same shop circuit as is connected to its armature, otherwise the machine might be left with its armature across one shop circuit and without a field, owing to the blowing of some breaker on the other circuit. The machine would then try to run away.

It is often necessary to put a "dead load" on a motor when "pumping-back" is impracticable. A shop generator is then belted to the motor and loaded upon a rheostat. This method is often used in testing the smaller motors, both series and shunt, as well as induction motors. A few of the larger induction motors are belted to generators which pump directly back on the "shop." The power for loading induction motors is obtained from shop alternators belted to direct current motors. These machines are located near the test so that their speed can be controlled with the motor field.

While generators may be tested by the electrical loss supply

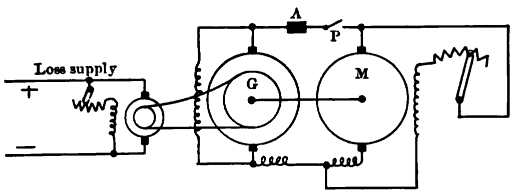

FIG. 4.— TWO COMPOUND GENERATORS PUMPING BACK.

method of Fig. 3, it is not customary to do so, principally because the voltage must be controlled by external means which would make it difficult to adjust the series field shunt in compounding the generator. All small generators up to 200 K. W. capacity, and some larger ones, are therefore loaded directly on water rheostats.

Direct current generators are sometimes "pumped-back" by the mechanical loss-supply method shown in Fig. 4. Two similar machines, which are to be tested, are assembled on a shop shaft and bearings and are directly connected. A smaller motor is then belted to the shaft which drives the machines and supplies all

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losses. The two armatures and series fields are connected in a closed circuit. The shunt fields are connected in the usual way, — a short shunt for the generator and a long shunt for the motor. The generator field is allowed to build up and then the motor is paralled with it by means of a voltmeter across the switch P. The set is loaded by weakening the motor field until normal current flows through the ammeter shunt (A). By this method the German silver shunt across the series field of the generator may be adjusted to give the proper compounding under load. The set may be reversed, the other machine now running as generator to have compounding adjustments made. The heating of the motor field will be less, and the heating of the motor commutator will be greater, than in the case of the generator, due to the weaker field and greater field distortion.

The following readings were taken on a pair of generators tested by this method. Their rating was MP–12–400–150.

	Generator	Motor
Volts across machine	123.5	122.5
Amperes line	3340.	3340.
Volts field	93.2	58.
Amperes field	38.8	25.7

Often a generator is pumped-back on a shop motor, either belted or direct-connected to it. One motor of 1100 horse-power and 550 volts is available for testing large railway generators. It is mounted on a permanent concrete foundation upon which the new generators may also be mounted and coupled to it.

Motor generator sets are easily loaded on water rheostats, the motor taking power from a shop alternator if a large enough one be available. Sometimes, when the motor of the set is a 25 cycle synchronous motor, and when a large rotary converter happens to be in the shop at the time, the converter is pressed into service to supply power to the set. The converter can be run inverted from the "500 shop," using a booster in series to control the voltage. A 500 kilowatt frequency-changer set was tested in this way after having had open-circuit and short-circuit heat runs which proved

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unsatisfactory. In this case the pair of generators (MP–12–400–150) mentioned before were employed to boost the "500 shop" up to about 700 volts at which it was delivered to an inverted rotary converter. The 3-phase current obtained was again boosted about 50 volts by an induction regulator and supplied to the low tension side of a bank of transformers. These stepped it up to 13,000 volts at which it was supplied to the 25 cycle, 530 kilowatt synchronous motor of the set under test. This was connected to a 62.5 cycle, 500 kilowatt, 4000 volt generator. Another bank of transformers stepped this power down to 2000 volts to be dissipated in six water rheostats (two in multiple on each phase). All these boostings and transformations were necessary owing to the limitations of the shop apparatus.

In the case of another direct-connected set which it was desired to load, the alternator to be used for power was smaller than the motor. The shop alternator's rating was, A T B–20–500 K. W.–360, the motor driving it was an M P–6–500 K. W.–300. The set contained a quarter phase induction motor, I Q–12–900 H. P.–500, 2300 volts, driving a direct-current generator, M P–8–600 K. W.–500, of about 600 volts. This set was run inverted, the generator taking power from the "500 shop" through a booster, and driving its motor as an induction generator. Part of the load was dissipated by four water-rheostats (two in multiple across each phase), and a part was "pumped back" on the alternator running as a synchronous motor and supplying the induction generator with exciting current, and also running its motor as a generator "pumping-back" on the "500 shop."

(To be continued.)

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THE BELT CONVEYOR.

By Harold Sumner Farnham, '06.

[From a lecture before the Mechanical Engineers of the class of 1906 on April 10, 1906].

The belt conveyor is a mechanical apparatus for conveying coal, ash, sand, cement, ore, stone and many other similar materials. One of its most common uses is for conveying coal from vessels or railroad cars to the power house, and for carrying away the ashes from the station, but it is also used extensively for carrying stone, cement, clay, coke, concrete material, earth, excavated material, gravel, limestone, ore of all kinds, sand, slag and waste material. In fact the belt conveyor is advantageously used in every operation where there is any material to be conveyed. It has already generally taken the place of the bucket system of conveying, which is noisy and heavy and hence needs more power to run it, and which is continually in need of repairs.

The fundamental principle of the belt conveyor is the perfect separation of the conveying parts from the running parts. The material is received directly on the belt, and carried, with no friction, to its destination. There is no jamming or clogging as seen in the old scraping systems; nor are there any joints, bolts or other projections to break or wear out. There are but two component parts, a belt, usually of rubber, and fixed sets of pulleys. The material never comes in contact with the pulleys to retard or clog their action. The two parts of the system act independently, and each with the highest efficiency. The point where the load is received is the only point of friction between the material and the belt. The advantage in this respect over any form of flight conveyor, in which the friction is constant along the haul, is surely apparent. Every reduction in friction means, not only a corresponding reduction in the power required for operation, but also saves breaking the material conveyed, and insures longer life for

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every part of the conveyor. On account of the extreme simplicity of the belt conveyor, repairs are largely avoided. The best belt systems convey noiselessly, a fact which alone shows high efficiency. They require little attendance, thereby saving considerable cost of labor. They are easily and quickly installed.

This article deals to a great extent with the apparatus of the Robins Conveying Belt Company of New York, this being the standard used in this country and abroad, and embodies the latest improvements in this line of engineering. This company has extensive works at Passaic, New Jersey, where all their apparatus is manufactured.

The most important part of a belt conveyor is the belt. The Robins belt is of rubber on both sides, this being thicker on the top or carrying side of the belt. The inside is made of cotton duck to give it sufficient tensile strength. The rubber covering is of extra thickness over the center of the belt on the top or carrying surface in order to stand the harder work enforced upon that part. Also, since the belt has more rubber and less canvas in the center, it will be more pliable and better preserve the curved shape which it has when running over the pulleys, or idlers, as they are called. This belt has been severely tested with the result that, when exposed to the wear of coal, ore, broken stone or other sharp and heavy substances, it has outlasted many times over its own thickness of nickel steel. This rubber belt is not affected by water, heat or cold or any ordinary chemical agencies. The only material which will injure rubber is oil, and no oil is used to lubricate the conveyor, as will be shown later. To prevent wet, sticky materials from clinging to the belt, revolving brushes are used. The brush is placed close to the belt as it bends around the head pulley; it takes its motion from the head shaft.

The head end of a belt conveyor is not, as often supposed, the end where the material is fed to the belt, but it is the discharge end. The material is fed to the belt in various ways: — from a crusher or rolls, from bins or chutes, either at one or at various points, or it is sometimes fed by a steam shovel, and often by hand. The best results are obtained when the material is fed to the belt continuously, and with the least possible shock. The life of a

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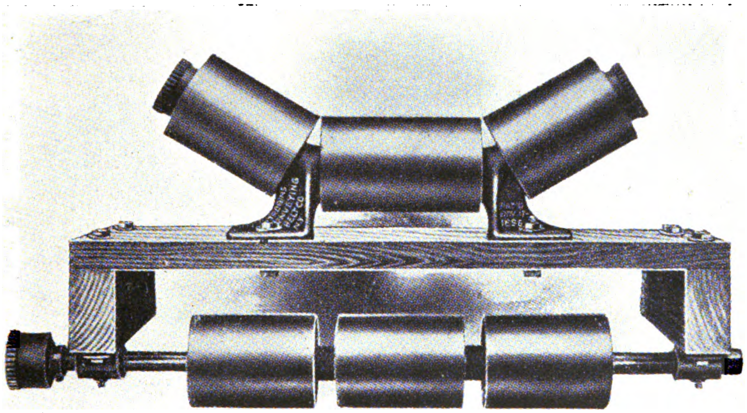
belt is greatly dependent upon these conditions. But any belt, however good, may be quickly destroyed if supported by defective idlers.

These idlers are an important part of the belt conveyor. They are made in many forms. The Troughing Idlers, used to support the loaded belt, consist of cast iron pulleys or pressed steel running on hollow steel shafts, which, in turn, are held in cast iron brackets. Return Idlers, for the return or empty belt, are the same as these excepting that all pulleys are on the same horizontal axis, and the pulleys are a little farther apart. These idlers are lubricated by forcing grease into the shafts with compression grease cups. Each cup holds about one pound of grease, a sufficient amount for several months running.

The spacing of idlers varies according to the width of the belt and the weight of the load. With wide belts or heavy loads the



Troughing and Return Idlers.

idlers are placed near together; while with narrow belts or light loads the intervals may be increased. Accordingly troughing idlers are placed from three to five feet apart, and return idlers from eight to twelve feet apart. Sometimes idlers are used as guides for the belt. Idlers for this purpose consist of two pulleys one on each side of the belt. The axes incline toward the middle

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of the belt so that the belt will not slip up over the pulleys. Idlers of this kind are used on long belts at intervals of about forty feet. Often where the belt goes over a pulley, these guide idlers are placed just behind the pulley, to make sure that the belt will not run off.

Hollow shafting is used in all idlers. The grease, forced through the shaft by the compression grease cup, enters the bearing at the center, and is forced out toward the ends where it forms a collar which keeps out dust and dirt. These compression grease cups are made of cast iron. They hold from three to ten ounces of grease according to the size used. The grease which is used must stand extremes of heat and cold without melting or getting hard. It must also be of such a consistency as to permit its being easily forced through the hollow shafts. To force grease into the bearing it is only necessary to screw in the cup until grease appears at the ends of the bearing. As already stated, the contents of one grease cup will last several months. The collar of grease formed at the ends of all bearings makes them dust proof; oil can not be used for this purpose.

As the majority of plants where coal and ore are handled are of wooden construction, the shafting is liable to settle and get out of line. For this reason the bearings are of the ball and socket type, which allows a certain amount of play without cramping the shaft. Such plants also are very dusty, and for this reason the bearings are lubricated in the same way as the idlers — that is, by forcing grease from the center outwards, so as to form a collar of grease which makes the bearing dust proof.

At one end of every belt conveyor there is placed a take-up or belt tightener to take up the slack in the belt when it stretches when new. In the Robins' "Protected Screw Take Up" the screw is entirely enclosed by the cast iron case, and therefore will not get clogged with dirt or rust. The bearings are of the ball and socket type so that the shaft will not jam even if the bearings are adjusted unequally. They are lubricated with grease as described above. A wrench for adjustment is fastened to this device.

A tripper is used when it is desired to have the conveyor dis-

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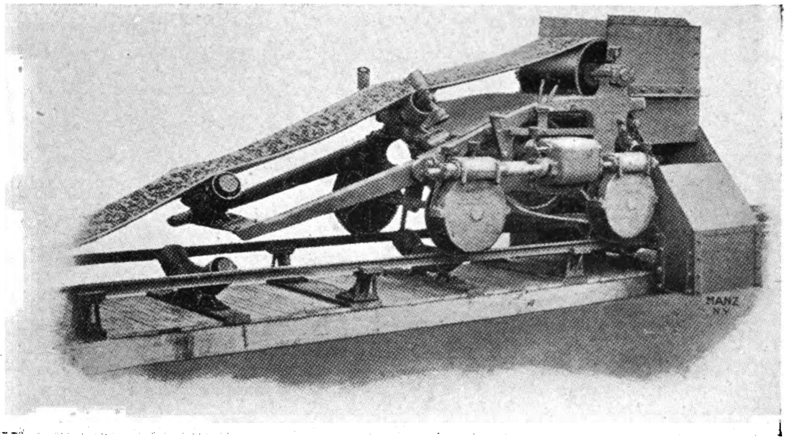
charge its load at any point other than at the head end. In its simplest form it may be described as consisting of two pulleys placed one above the other, the belt running over the upper and under the lower one, in a course like that followed in tracing the letter S. Where the belt makes its first turn downward it discharges its load into a chute leading to one side of the conveyor.

The tripper may either be movable or fixed, and may be used either singly or in series. Movable trippers are used when it is desired that a conveyor discharge its load evenly along its entire length, as, for instance, into a continuous row of bins. Fixed



AUTOMATIC TRIPPER.

trippers are employed to discharge the load at certain definite and somewhat separated points.

Movable trippers are made in two forms, "Hand-driven" and "Automatic." The "Hand-driven" is moved from point to point by means of a hand crank. The "Automatic" tripper is propelled by the motion of the conveying belt, which is connected through gearing with the driving wheels. It reverses its direction automatically at either end of its run, thus travelling constantly back and forth all the while distributing its load as it moves. It can be stopped, reversed or made stationary at will.

The operation of the fixed tripper is made automatic by having

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it deliver into a two-way chute, one branch of which delivers into the hopper or bin alongside the conveyor, the other branch leading back upon the belt. When the hopper is full, the material backs up in the side chute and flows into the straight chute, from which it is returned to the belt. It is then carried to the next tripper, where it is discharged, until the hopper at that point has been filled also, when it is again carried to the next, and so on.

The capacity of a belt conveyor is largely dependent upon the size of material carried. Belts are made as narrow as 10″, and from that size up to 48″ every 2″ in additional width. For special purposes belts have been made as wide as 60″. The usual operating speed of a belt conveyor is 200 to 400 feet per minute, although they may run with safety as high as 700 feet per minute, the wear increasing proportionally.

The average capacity of a flight conveyor is about 50 tons per hour, that of a bucket conveyor is 150 tons per hour, while the average capacity of a belt conveyor of medium size is about 500 tons per hour.

Belt conveyors may be driven by motors, engines, countershafts or any form of rotary power. The engine or countershaft may be belted or direct connected by gears to the head pulley of the conveyor. Often they are direct connected and driven by a high speed, back geared electric motor, a second pair of gears being required to reduce the speed. Power may be applied at either end of a belt conveyor, or at any intermediate point, although it is slightly advantageous to drive the conveyor from the head or discharge end.

It is important and interesting to study the arrangements of the belt conveyor regarding its inclination. The incline at which the conveyor will work depends upon (1) The consistency of the material conveyed, and (2) The method in which the material is fed to the belt. If the material is damp or wet, and so tends to adhere to the belt, the incline can be steeper. If the material is fed continuously to the belt the incline may be steeper also.

Now as to the actual inclines which are used. With the larger sizes of cobbles or boulders up to 30″ the maximum safe inclination of a conveyor is 18°. With smaller sizes of stones up to 4″, con-

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tinuously fed to the conveyor, a safe angle is 20°. With dry sand or gravel 22° is safe; and if these are damp they may be carried at as steep an angle as 25°. Material in the form of porridge can be carried at only a slight inclination depending on its consistency. Material may be carried down hill on a belt conveyor as well as up an incline. When possible, it is good practice to place an elevating conveyor on a curved incline. The radius of this curve can not be less than about 300 feet, for if it were, the belt would pull and fail to ride in its proper position on the idlers.

In short, belt conveyors may be operated either level or inclined or a combination of these. They may discharge their load at one end or may be reversible and discharge at either end; or, if desired, they may be discharged at any point along their length by means of movable or fixed trippers which have already been described.

Belt conveyors are much used by miners and shippers of anthracite coal because they handle the coal with the least loss from breakage. There is no breakage along the line of the conveyor because the coal is at rest while on the belt.

The new crushing and separating plant of the New Jersey Zinc Company represents in arrangement and equipment the most advanced stage in ore dressing practice. In this plant there are over one hundred and thirty belt conveyors of the Robins type.

At the Homestake Mining Company of So. Dakota, there are three conveyors each 167 feet long. Each belt carries about 160 tons per day. They run at moderate speed and are driven from a single shaft at the discharge end, requiring about 3 h. p. each.

At Port Henry, New York, the magnetic separating plant for iron ore is equipped with several 20″ conveyors. The one carrying the ore to the railroad cars for shipment is 200 feet long and runs at an angle of 24°.

Sorting conveyors are now taking place of sorting tables in mining processes. For this purpose the belt is run very slowly, and the material is sorted and broken up by workmen while it is being carried along on the belt. This saves much time over the old method, and the process is much cleaner. The belt speed is about 35 feet per minute for this work.

In one of the mills of the Alpha Portland Cement Co. many belt

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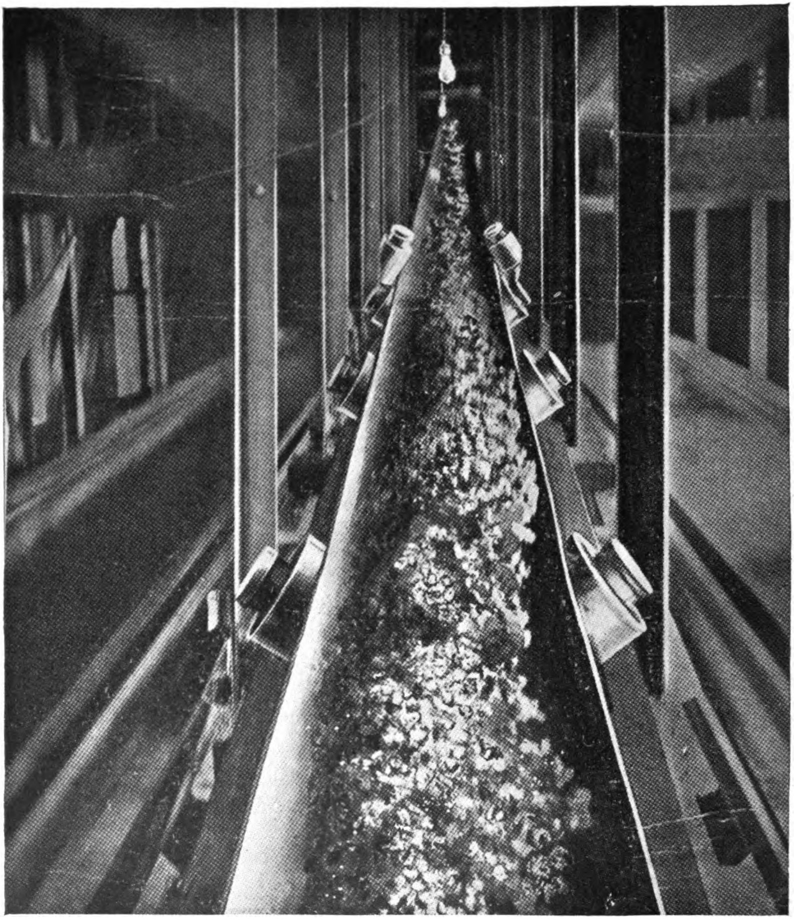
conveyors are in use. All the elevating and conveying of the whole cement-making process, with the exception of handling hot clink-



CONVEYOR HANDLING ASHES.

ers, is done with belt conveyors, many of which are run at an angle of 25°.

Conveyors are useful in building subways, as they afford an easy way of carrying to the surface material removed from below. In constructing the New York subway they were extensively used for this purpose.

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Gas plants make use of belt conveyors for carrying coke, coal and oxide. The New England Gas and Coke Co. at Everett use several for this purpose. The Consolidated Gas Co. of New York, the Montreal Gas Co. and the Lowell and Springfield Gas companies use these conveyors.

The best ash conveyor for small amounts of ashes is undoubtedly a steel car, but in large plants the quantity of ashes is so great that some labor saving device is needed. In this conveyor pure rubber is the only material which comes in contact with the substance conveyed. For this reason the conveyor is entirely unaffected by the sulphurous acids which are present in all coal ashes, and which have a strong corrosive effect on iron and steel. A revolving brush effectively removes anything which may stick to the belt, and thus prevents dripping of ashes and water on the return run. All the ashes produced at the Ninety-sixth Street power plant of New York are carried away by a 16″ belt conveyor of this type. This plant has a capacity of 70 000 h. p., so the ash problem is a serious one.

A contrast with the old-fashioned bucket system of conveying is shown at the works of the South Side Elevated Railway of Chicago. Under the method formerly used it took ten men working day and night to handle the 200 tons of coal. With belt conveyors the 200 tons are all stored during the day time by only six men.

The cost of shipping coal and ore can be much reduced by using a belt conveyor instead of cars to carry the material from shore to the vessel. The weight of a Robins Belt Conveyor carrying 750 tons per hour, combined with its load, amounts to an evenly distributed load of about 100 lbs. per foot. Comparing the power necessary to carry this small load with that required to support a moving train of loaded cars shows a tremendous difference in the first cost of the two systems. Then the belt conveyor requires less attendants than the car system, and it handles more material per hour.

The cost of concrete, when made in large quantities, can be greatly reduced by employing belt conveyors for carrying the component parts to the mixer. In building the foundations of the

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120 000 h. p. station of the New York Gas and Electric, Heat and Power Co., belt conveyors were extensively used. Sand and stone were carried on a 30″ belt at an angle of 20° to the hopper of the mixer. On account of very contracted space, it was only possible to build small storage bins which required frequent filling, but, for all this, excellent concrete was made at the rate of 30 cu. yds. per hour with a total force of five men including the engineer.

At the Great Northern Paper Company in Maine a 20″ belt, running at an angle of 22°, carries chips into the paper mill. It carries in ten hours all the chips produced from 100 cords of spruce wood, and to do this requires an electric motor of 10 h. p. There are seven other conveyors for chips and coal at this plant.

Often portable conveyors are used for loading and unloading vessels, barges and cars, for stacking coke, carrying material from excavations, and other purposes. These portable conveyors are entirely self contained, and consist of a belt conveyor mounted on a light steel frame, and driven by a direct geared engine or a motor. The frame is light but strong, and is built in short, separate sections, which are bolted together. By leaving out or putting in one of these sections, the length of the conveyor may be varied with little trouble. The engine or motor is entirely enclosed and protected from dust, as also are the bearings.

On dredges the width of the belt conveyor varies from 20″ to 30″ depending upon the size of the largest stones. The angle of inclination may be made from 18° to 20° for this class of work.

The belt conveyor is specially adapted for general mining work, as it is indestructible by ordinary agencies such as water, heat, cold, etc., and is light in weight per linear foot, which makes it easily movable from place to place. A movable conveyor is mounted on two wooden stringers placed on cross timbers. When it is desired to move the conveyor sideways it is barred over in much the same way that a railroad track is thrown. To move it endwise rollers are placed under the stringers, and the conveyor belt itself furnishes the motive power, an electric motor being mounted on the structure at one end.

One of the most complicated parts of the handling of gravels and sands by belt conveyors is the proper initial loading of the

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material on the belt. The material is sometimes damp or wet, and even in the form of a porridge. If it is handled by a steam shovel, it must first be dumped by the shovel into a large movable hopper over the belt. If there are heavy boulders a grizzly must be placed on the mouth of the hopper to prevent these from being fed to the belt. If the material is wet and sticky the hopper must be equipped with a mechanical shaking feeder.

The Brooklyn Heights Railroad Co. have a most economical plant for handling coal. Coal from barges is conveyed by belts to a storage place holding 100 000 tons. From here the coal is taken as desired by other conveyors. Coal, at this plant, is taken into or out of storage at the rate of 200 tons per hour, and at a very low cost per ton.

The new Edison Electric Illuminating Company's plant at So. Boston is equipped with belt conveyors for handling coal. Coal is conveyed from the barges to the storage pile at the average rate of 125 tons per hour. From here it is carried by other belts to a large crusher and thence to the boiler house.

The O'Rourke Engineering Construction Company at Riker's Island, N. Y., is where from 4000 to 5000 cu. yds. of ashes and refuse are each day unloaded from scows and distributed over a large area of low land. The arrangement of the plant is as follows: The scows are unloaded by a pair of cranes. These deliver into a hopper which feeds the first belt conveyor. This belt is five feet wide, and carries the material to the distributing conveyor which is 1000 feet long. Power is applied at the tail end where the load is received, and the entire conveyor is moved sideways as the work progresses. The conveyor discharges its load through a movable tripper which itself carries a short auxiliary conveyor, by which the material is projected a considerable distance to one side. Moving this conveyor, as often as the low land becomes filled to a sufficient height, is not as tedious an operation as may be imagined. It is necessary to move this particular conveyor only once in two or three weeks, and it requires less than a day to change its location.

At the works of the Dominion Coal Co. at Cape Breton, there is a system of 36″ belt conveyors having a total length of about

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1000 feet. The arrangement is extremely economical here, for ships of 5000 tons capacity arriving on one high tide are regularly loaded and dispatched on the following tide, the rate of loading frequently exceeding 800 tons per hour.

To appreciate the durability of a belt, we may refer to a dredge in operation in France. The conveyor is of such size that it will carry off large boulders, stones weighing over 500 lbs. being frequently encountered.

The New York Subway Power House of 120 000 h. p., the largest in the world, represents the most improved practice in every department, including the handling of fuel and ashes. This plant is thoroughly equipped with belt conveyors. Coal is conveyed to the station at the rate of 200 tons per hour, being elevated 110 feet at the same time. Hot ashes are first carried from the boiler house by steel cars hauled by an electric locomotive. The ashes are then carried away by a series of belt conveyors.

By all these examples of what belt conveyors are doing, we must conclude that their use is almost unlimited. Wherever material is to be carried from place to place there is no cleaner, quicker or cheaper way than by the use of belt conveyors.

The cost of maintaining a belt conveyor is slight. It needs little attention, running automatically. The expense for lubrication is small. It is such a simple piece of apparatus that repairs are largely avoided, and so time required for expensive shut-downs is saved. The only part of a belt conveyor which can wear out is the belt, and the cost of the Robins belt is about 20% the cost of the whole conveyor. The average life of the Robins belt is seven years, but with careful usage one will last much longer. An injured belt may easily be repaired by replacing the defective section by a new piece of belting, suitable metallic belt lacing being made for this purpose. An allowance of 5% per year for repairs is ample.

The first cost of a belt conveyor for an equal capacity is much less than of other more complicated forms of conveying machinery. The approximate cost of belt conveyors per linear foot for a few standard sizes is: for a 14″ belt \$6.00 per foot, for a 24″ belt \$12.00 per foot, for a 36″ belt \$20.00 per foot. These approximate values

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include all parts of the conveyor except the distributing trippers which cost from $300. to $600. apiece. A 24″ belt, common size used, 200 feet long, all set up in place would cost according to the above figures about $2700. Of this first cost the belt alone costs about $600. Since the average life of a belt is seven years, the cost per year is less than $100. or about 3% of the total cost. This simply advances the economical side of the belt conveyor, but is an important side to bring out, because the manufacturer of today is looking for apparatus that will give the greatest results at the least cost. This is exactly the reason why, in most modern plants, we find the belt conveyor used for handling material of all kinds.

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A NEW TYPE OF MICROMETER.

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(Austin Teaching Fellow in Engineering.)

OFTEN, engineers would like to know the effect of actual live loads upon the structures which they have designed, if only for the sake of knowing how nearly correct were the assumptions and data used in their calculations. The effect of loads upon structures such as dams, bridges, and buildings, and the effect of shocks on moving trains, ships, etc., are usually apparent only in the microscopic stretching of the parts. When this stretching can be measured, much can be learned concerning the strength of structures and materials. Unfortunately, since the first requirement is accuracy to the nearest $\frac{1}{50\ 000}$ in. or better, such measurements involve much time and labor when made with any known type of instrument. Nevertheless this work is carried on in testing laboratories and sometimes in the field.

Below is described a new type of micrometer which the writer has lately designed for such work. It is called a rolling lens micrometer and its chief merit is its ease of manipulation. The particular instrument described here is an extensometer for measuring the elastic compression of concrete, and may be rated as a portable, direct reading micrometer, sensitive to the nearest $\frac{1}{50\ 000}$ in., with a range of $\frac{200}{50\ 000}$ in.

As indicated in Fig. 1 the apparatus consists of two moving parts of glass, mounted on the end of a frame. The frame rests at one end on a short leg, and at the other end, on a small pivoted roller. On the top surface of this roller is mounted a perfectly flat eye-glass.

The second part of the apparatus is a convex eye-glass (160″ radius of curvature), mounted on a short hinged arm so as to rest always flat against the first glass. On account of the curvature the two lenses touch only at one point.

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When the above combination is held against the surface of the material to be tested as shown in Fig. 1, any shrinking or stretching of the surface under the instrument will cause the small roller to turn beneath the frame and so tilt the attached glass.

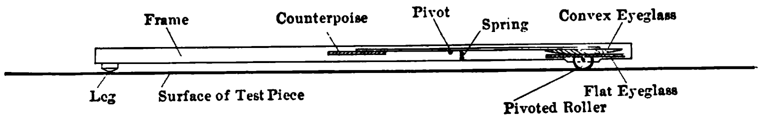

FIG. 1.— POSITIONS OF PARTS AND OUTLINE OF FRAME.

This, then, lifts the second glass slightly with a cam-like action.

As the lenses have small curvature this motion is accompanied by a very rapid shifting of the point of contact.

Thanks to the interference phenomenon of light, known as Newton's rings, this shifting of the point of contact is visible, so that when the roller turns, a small target of colored light (about $\frac{1}{8}$ in. diameter) is seen to travel swiftly with the point of contact in the space between the glasses. Its motion is five hundred times more rapid than the original motion of the roller. By observing the positions of such a target it is possible, with suitable design, to measure distances within a few millionths of an inch, automatically and with ease. In the present case the motion of the target was designed to be approximately uniform and about 500 times greater than the travel of the roller. Since the target itself is sharp and clear enough to be located to the nearest $\frac{1}{100}$ in., the apparatus will detect a displacement of $\frac{1}{50\ 000}$ in. The target position is read by the aid of a paper scale, pasted on the upper glass along the straight path which the target follows.

If such a machine as the above were made with a frame 20 in. long then $\frac{1}{50\ 000}$ in. would represent $\frac{1}{1\ 000\ 000}$ of the length under observation, so that stresses of 30 lbs. per sq. in. in steel would produce visible effects, and stresses of 3 lbs. per sq. in. in concrete and wood could be observed.

The curves in Fig. 2 and 3 give some idea of the delicate measurements that can be made. In Fig. 2 the diagram shows the elongation during flexure for a 16 in. length of the under surface of a

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reinforced concrete beam, from the time when the load was 800 lb. to failure at about 5000 lb. The beam was 88 in. long, 3 in. wide, 9 in deep and had ¼ sq. in. of steel 1 in. above the bottom. The load was applied by the testing machine at two points 22 in. from each end support.

The rise of the curve represents the elongation of the concrete surface for the loads mentioned on the lower line. The whole curve is the history of a total stretch of $\frac{17}{1000}$ in. and is the result of about ninety micrometer observations. The numerous breaks in

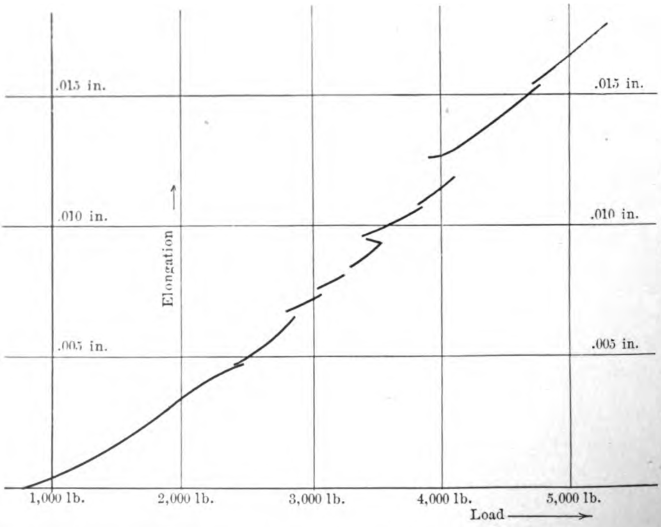

FIG. 2.—ELONGATION OF THE LOWER SURFACE OF A CONCRETE BEAM DURING BENDING.

87 observations were plotted all of which lie within the thickness of the curve.

the curve show the sudden partial failures and cracking of the beam.

In this test, the extensometer was h[illegible] the bott[illegible] the beam by a rubber band. T[illegible] ously until the target of the ext[illegible] of its scale. The machine w[illegible] the target was set back to t[illegible]

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just six halts of this kind and at other times the micrometer measurements and the loads on the beam were read off as fast as a man could talk.

Fig. 3 shows the compression curve of a short 6 in. × 6 in. concrete pillar. The various loads in lbs. per sq. in. according to a 200 000 lb. testing machine are recorded on the bottom line and the rise of the curve represents the corresponding compression along one surface for 16 inches of the pillar's length. This compression amounts to about $\frac{4}{1000}$ in. at a load of 700 lbs. per sq. in. so that a coefficient of elasticity in indicated of about 2,800,000 lbs. per. sq. in.

The essential features of this rolling-lens type of micrometer

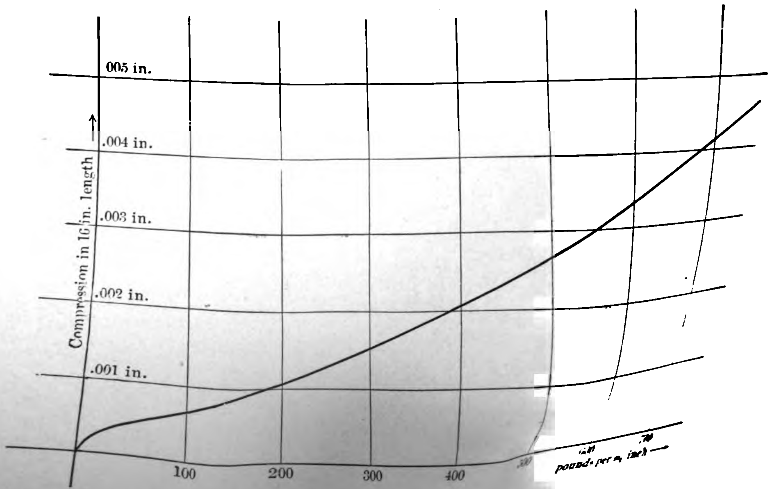

Fig. 3.—Compres... ncrete Pillar.
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glasses is shifted. Having once located the spot, it can still be seen with only a very light pressure of the glass. Furthermore, with a dark background it may be seen in almost any light, and with lenses of more closely fitting curvature its size and brilliancy are many times increased, while its motion is very great for a small rocking of the lenses.

In closing, it would be well to note that after such lenses have been incorporated in a measuring device, there will be no difficulty in calibrating the instrument, for this can always be done by using the small motion obtained by reducing with a lever the motion of a good screw micrometer. The whole apparatus may then be carried around in the pocket and used anywhere at a moment's notice to do the work of an elaborate mirror and scale apparatus.

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ARCHITECTURAL PLATES.

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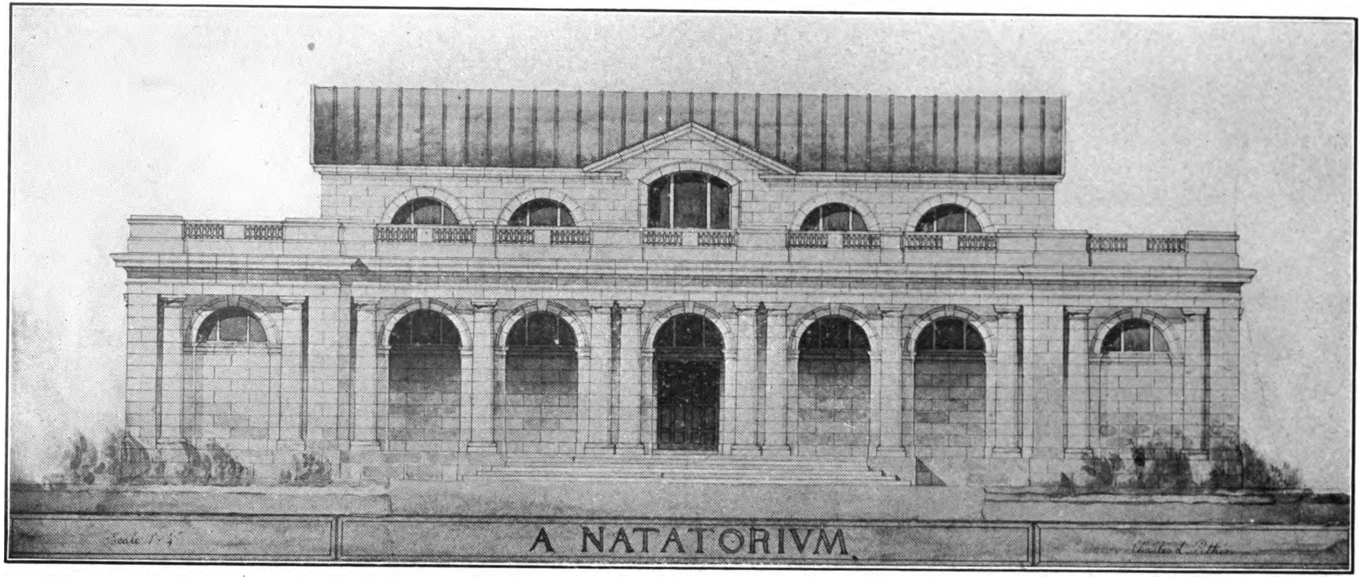

C. L. Pitkin. A Bath House. Second-Year Work.

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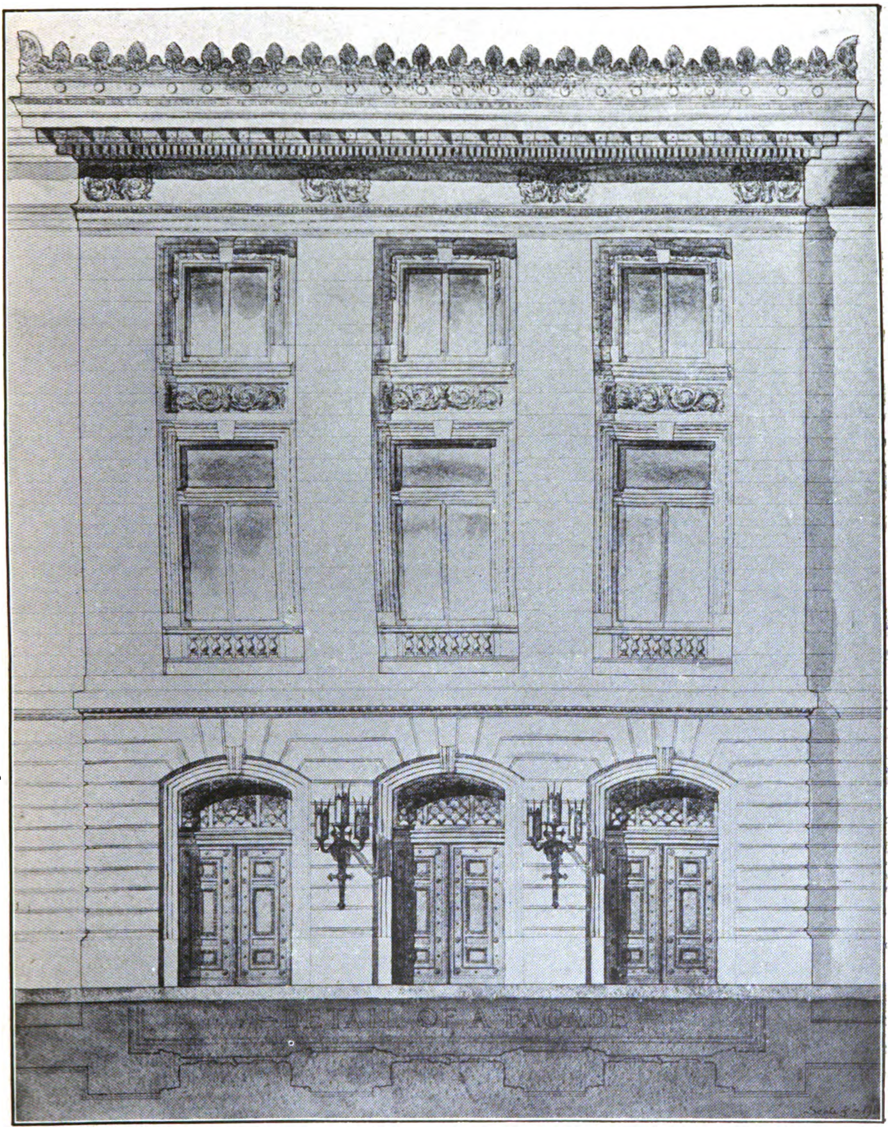

DETAIL OF A FAÇADE.

M. Feather. Second-Year Work.

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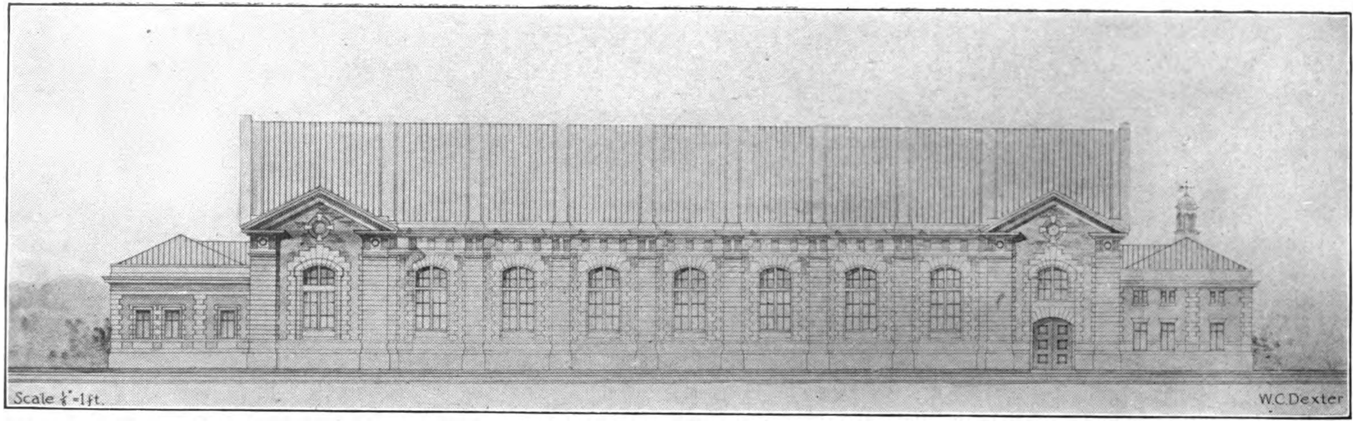

W. C. Dexter. A RIDING SCHOOL. Third-Year Work.

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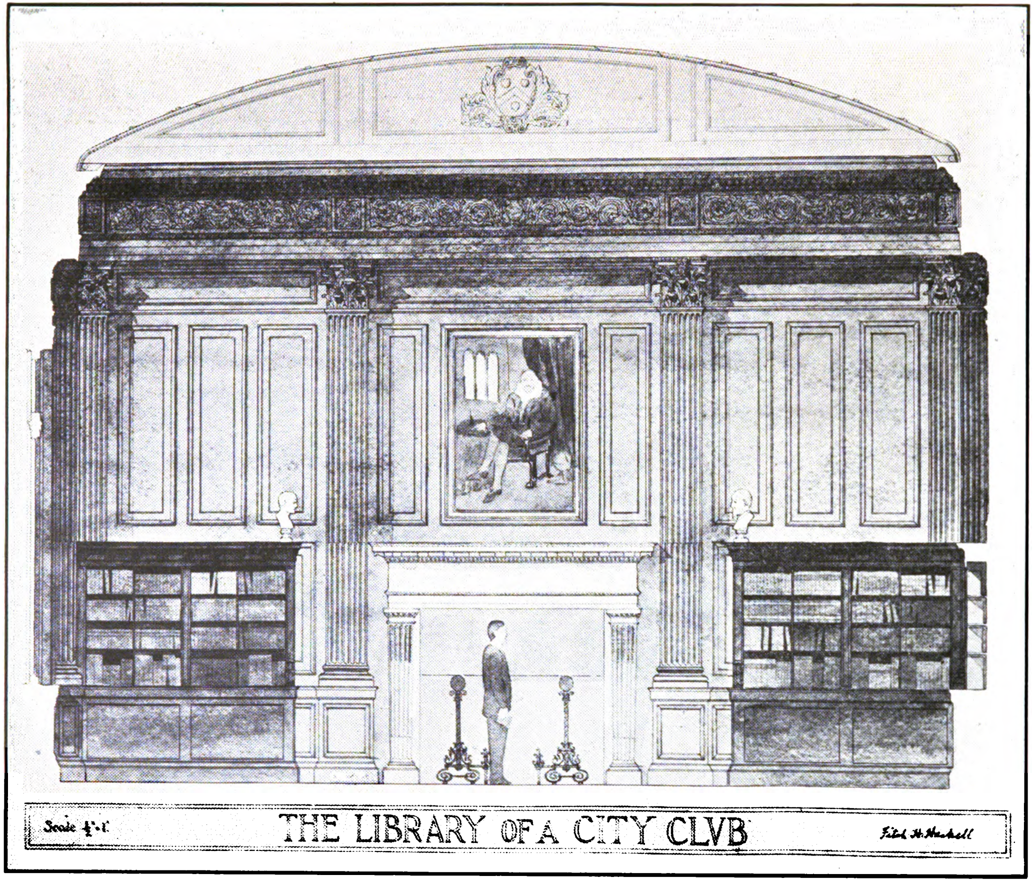

F. H. Haskell. THE LIBRARY OF A CITY CLUB. Third-Year Work.

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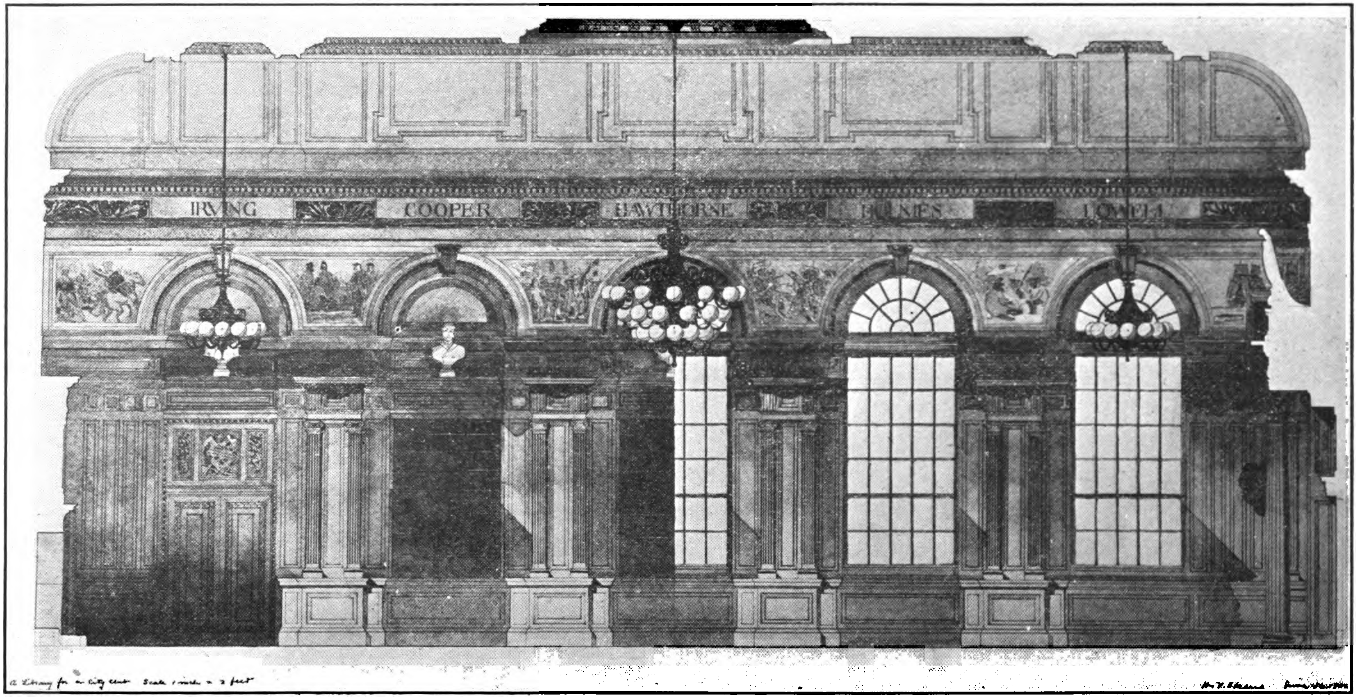

H. V. Skene. **The Library of a City Club.** Third-Year Work.

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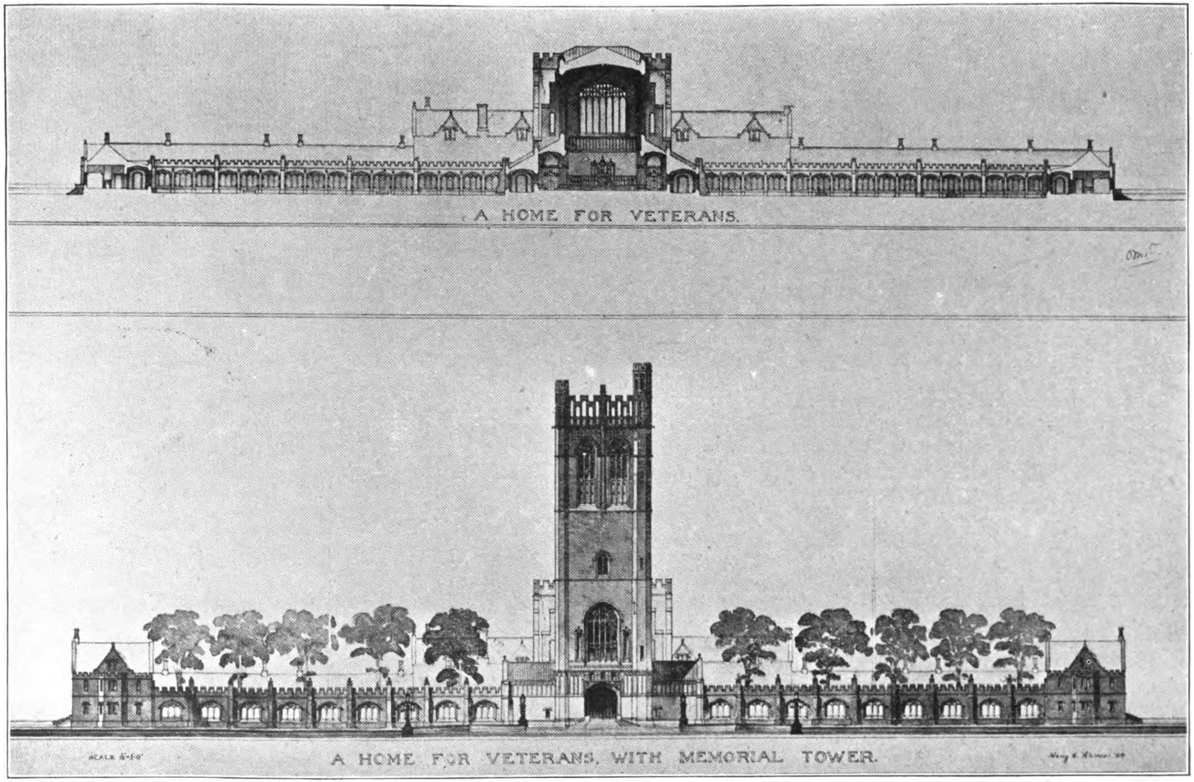

H. E. Warren. A VETERANS' HOME. Fifth-Year Work.

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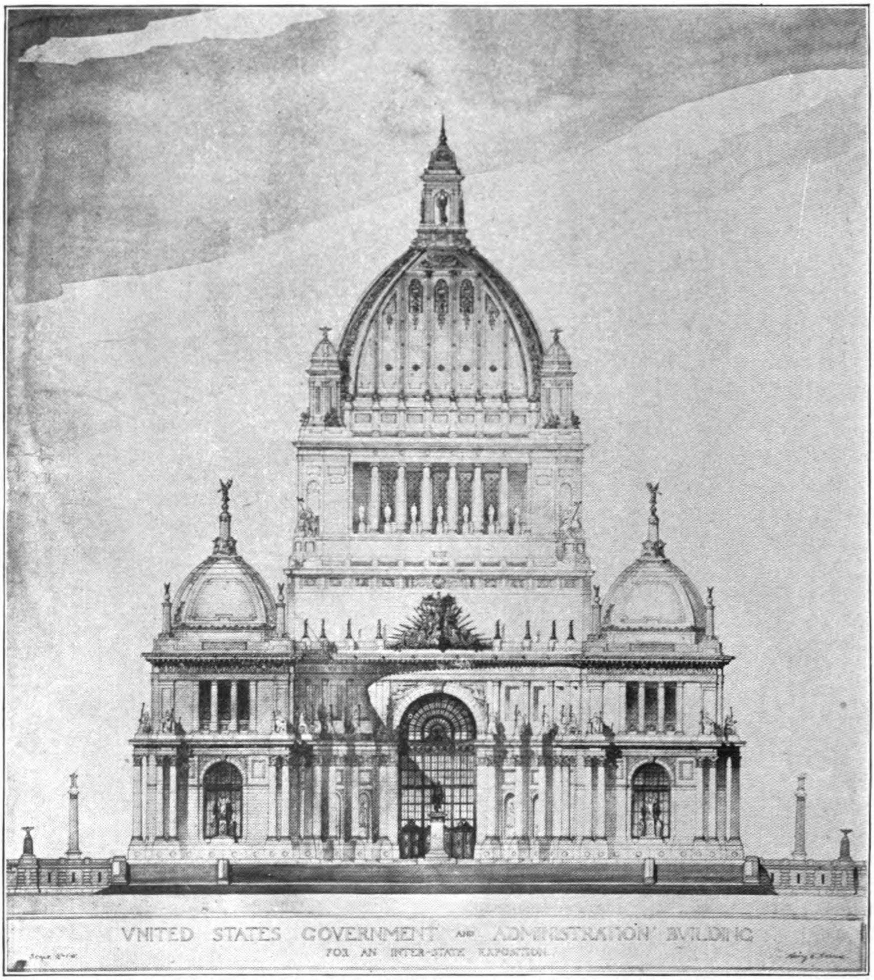

A Fair Building.

(Elevation.)

H. E. Warren. **Fifth-Year Work.**

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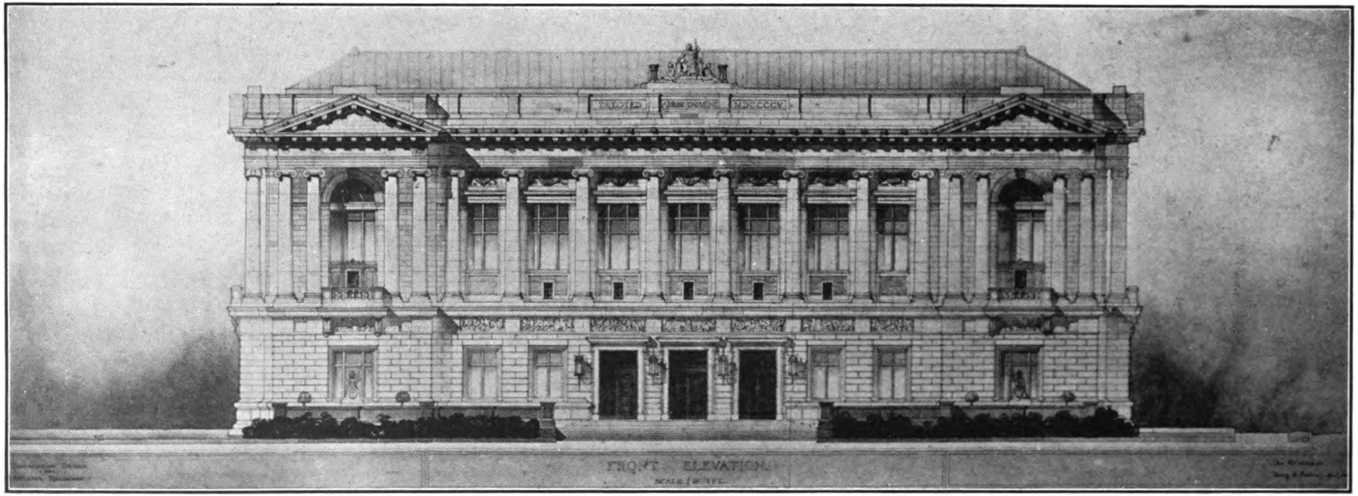

AN ATHENAEUM.
(Elevation)
H. E. Warren. Awarded the Appleton Travelling Fellowship 1905.

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HARVARD ENGINEERING JOURNAL.

A Quarterly

DEVOTED TO THE INTERESTS OF ENGINEERING AND ARCHITECTURE AT HARVARD UNIVERSITY.

Published four times during the college year by the Board of Editors of the Harvard Engineering Journal.

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Editorial.

At the April meeting of the board Prof. L. S. Marks who has been Auditor of the Journal, tendered his resignation, which was accepted. We take pleasure in announcing the election of Prof. F. L. Kennedy to fill the vacancy thus caused.

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Harvard Engineering Society.

The Engineering Society held its annual election of officers on Monday, April 30th. The following were elected:

President, Harry P. Forté '07; Secretary, Walter K. Cabot '07; Treasurer, Sidney Withington '06; Graduate Secretary, Walter C. Durfee '04; Adviser, Prof. I. N. Hollis.

The Annual Dinner of the Society was held in the Harvard Union on May 16th. It was especially honored by the presence of President Eliot, and Josiah Quincy, both of whom made speeches. Other speakers of the evening were Prof. E. C. Pickering, and Prof. W. M. Davis, Dean of the new Graduate School of Applied Science. Prof. I. N. Hollis was toastmaster. This dinner was a great success from every point of view, and we feel that more occasions of the kind would be cordially welcomed and supported by the Undergraduates of the Scientific School. Those who had charge of the arrangements for the Dinner are to be congratulated.

As a result of the recent elections in the different clubs, the following men have become members of the Executive Committee for next year: — H. P. Forté, Chairman; Prof. I. N. Hollis, W. C. Durfee, W. K. Cabot, S. Withington, W. C. Brinton, E. F. Burham, A. G. Cerda, I. B. Joralemon, C. A. Lewis, H. L. Lincoln, W. D. Thompson, and J. Tyng.

The first meeting of this committee will be held shortly after the beginning of next term.

Harvard Electrical Club.

The following lectures were given under the auspices of the Club: — Power Distribution on the Boston Elevated Railway, by Mr. C. H. Hile, on Jan. 22. Recent Developments in Single Phase Railway Work, by Mr. J. F. Vaughn, on April 24.

On May 14, Mr. W. A. Eaton, Chief Engineer of the Cambridge Electric Light Company, discussed some of the problems of a lighting engineer, and gave some of the reasons which led his company to adopt the A. C. series arc lamps now in use. The annual election of officers at this meeting resulted in the election

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the meeting held in October. Mr. Dutton, '01, who has been in the Philippines spoke on the sanitary projects of the United States' Government and the improvements of Manila harbor. At this meeting the following officers were elected for the year.

C. R. Mandigo, *President.*

R. Sickles, '07, *Secretary.*

C. E. Marsters, '07, *Treasurer.*

At the meeting in December, Mr. Killam of Peabody, Stearns & Co., Architects, spoke on Cataloging and Systematizing Engineering Practice and Experience. On January 17 a social meeting was held. As the purpose of the meeting was purely social there was no speaker. In the future the Club will meet monthly. The meetings have been well attended, the members are enthusiastic and the prospects for the future are very promising.

Graduate Notes.

The following men are working on the New York water supply:
R. M. Greenlaw, '02, G. S. Mumford, '02, Foster Towle, '06, and Allan Smith, '05.

C. M. Holland, '06, is with the Rapid Transit Commission.

T. C. Eayrs, '05, is in the Chicago office of the Westinghouse Electrical Co.

F. S. Farnham, '06, D. C. Crawford, and J. G. Hadsley, report from the Western Electrical Co.

C. C. Lee, '06, is with the Baldwin Locomotive Co.

N. J. Lupien, '06, is with the General Electrical Co. at Lynn.

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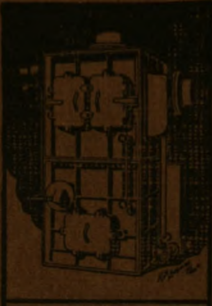

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